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Geology of a Portion of the Mount Holly Springs Quadrangle, Adams and Cumberland Counties, Pennsylvania

Jacob Freedman

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Progress Report 169

Geology of a Portion of the Mt. Holly Springs Quadrangle, Adams and Cumberland Counties, Pennsylvania

By Jacob Freedman
Cooperating Geologist
Pa. Geological Survey

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GEOLOGY OF A PORTION OF THE MOUNT HOLLY SPRINGS QUADRANGLE, ADAMS AND CUMBERLAND COUNTIES, PENNSYLVANIA

by

Jacob Freedman[1]

ABSTRACT

The principal problem in the Mount Holly Springs 7½-minute quadrangle is whether South Mountain is an anticlinal uplift or an overthrust block. Subsidiary problems involve the relationship of the Catoctin volcanics to the overlying clastics, the presence and constitution of the Loudoun Formation, distinction and subdivision of the Montalto Member of the Harpers Formation, the presence or absence of Harpers Phyllite, and the deformation sequence and pattern.

The stratigraphy from oldest to youngest is: Precambrian Metabasalt, and aporhyolite; Cambrian Loudoun Formation, Weverton Formation, Harpers Formation, Antietam Quartzite and Tomstown Dolomite. Subdivision of the rhyolitic rocks into aporhyolite, aporhyolite porphyry and lavender aporhyolite; the Loudoun Formation into muscovitic quartzite and muscovitic phyllite, and the Montalto Quartzite Member of the Harpers Formation, into "foliated quartzite," "vitreous quartzite," "blue quartzite," a key formation, and "greenish quartzite" provided control in mapping. Downfaulted against the Precambrian volcanics are gray and red Triassic sandstones and conglomerates. These were intruded by Triassic diabasic and basaltic dikes up to 110 feet thick.

The rocks have been regionally metamorphosed to the green schist facies with local contact metamorphism in the walls of the Triassic dikes.

The South Mountain anticlinorium is a culmination and a salient along the axis of greatest curvature in the Appalachian belt. Some of the oldest rocks in the Blue Ridge province of Pennsylvania have been raised to the surface and pushed northwest in a series of doubly plunging folds. To the northeast and presumably to the southwest, they plunge at gentle angles under the Tomstown Dolomite. Thickened crests and troughs and attenuated limbs indicate similar folding. Fourteen first order anticlines and synclines and a number of second order folds are identified. Where the Blue Ridge prong in Pennsylvania is at its widest and shows the curvature, the number of folds is a maximum.

The metavolcanic rocks show layering, S_1 cleavage and axial planes dipping dominantly to the southeast. This seems to indicate overturning to the northwest. The Cambrian clastic rocks are steeply asymmetric at higher levels but become overturned at lower levels. The Tomstown Dolomite is characterized by recumbent folding in the Philadelphia Clay Company pit.

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[1] Professor, Franklin and Marshall College, Lancaster, Pa.

There is possible evidence for more than one deformation involving both metavolcanic and clastic rocks. Structures found in one also occurred in the other, indicating that all deformations postdated the deposition of the Lower Cambrian sediments. The irregular northwest boundary of Piney Mountain, Trent Hill and French Hill and a breccia at the foot of Piney Mountain suggest a major thrust displaced from Stose's Reading Banks thrust. High angle faults have down-dropped the Mountain Creek Syncline underlain by Tomstown Dolomite in a graben, possibly as a result of relaxation of compression. The northwest edge of Mount Holly and Keller Hill seems to be partly conformable and partly a high angle, strike slip, left lateral fault. A number of high angle transverse faults resulted from differential stress following the folding and thrusting.

The earliest evident deformation is post Tomstown Dolomite in age. This could fit into a Late Ordovician orogeny about 160-180 million years ago. The common attitude of S_0, S_1 and S_2 indicate that possible subsequent deformations maintained a consistent stress distribution.

INTRODUCTION

LOCATION

The Mount Holly Springs 7½-minute quadrangle lies in the south-central part of Pennsylvania west of the Susquehanna River, near Harrisburg. The physiographic provinces covered by the Mount Holly Springs quadrangle include: 1. The Cumberland Valley, a narrow strip of the southeastern part of the Valley and Ridge province, 2. a part of the northernmost tip of the Blue Ridge province, 3. the Triassic Lowland section of the Piedmont province (Figure 1). The geologic setting of the area is shown in Figure 2. The area mapped is the southwest quarter of the Carlisle 15-minute quadrangle. Cumberland County takes in the northern part of the quadrangle, Adams County the southern part, and a small corner of York County the east-central part.

Critical areas were traversed to collect and describe small specimens from float and outcrop at short intervals. Altimeter readings provided locations along these traverses in heavily timbered mountainous areas. Large key outcrop areas provided detail for petrofabric structural data. Recognizable surfaces and lineations were plotted on the lower hemisphere of equal area nets. Aerial photographs and the Mount Holly Springs 7½-minute quadrangle enlarged to a scale of 1:1418 were bases for mapping details.

The field work on the Mount Holly Springs quadrangle was done during eight-week periods of the summers of 1958, 59, 60, and 61. This report was prepared and revised during parts of the summers of 1962, 1963, and 1964.

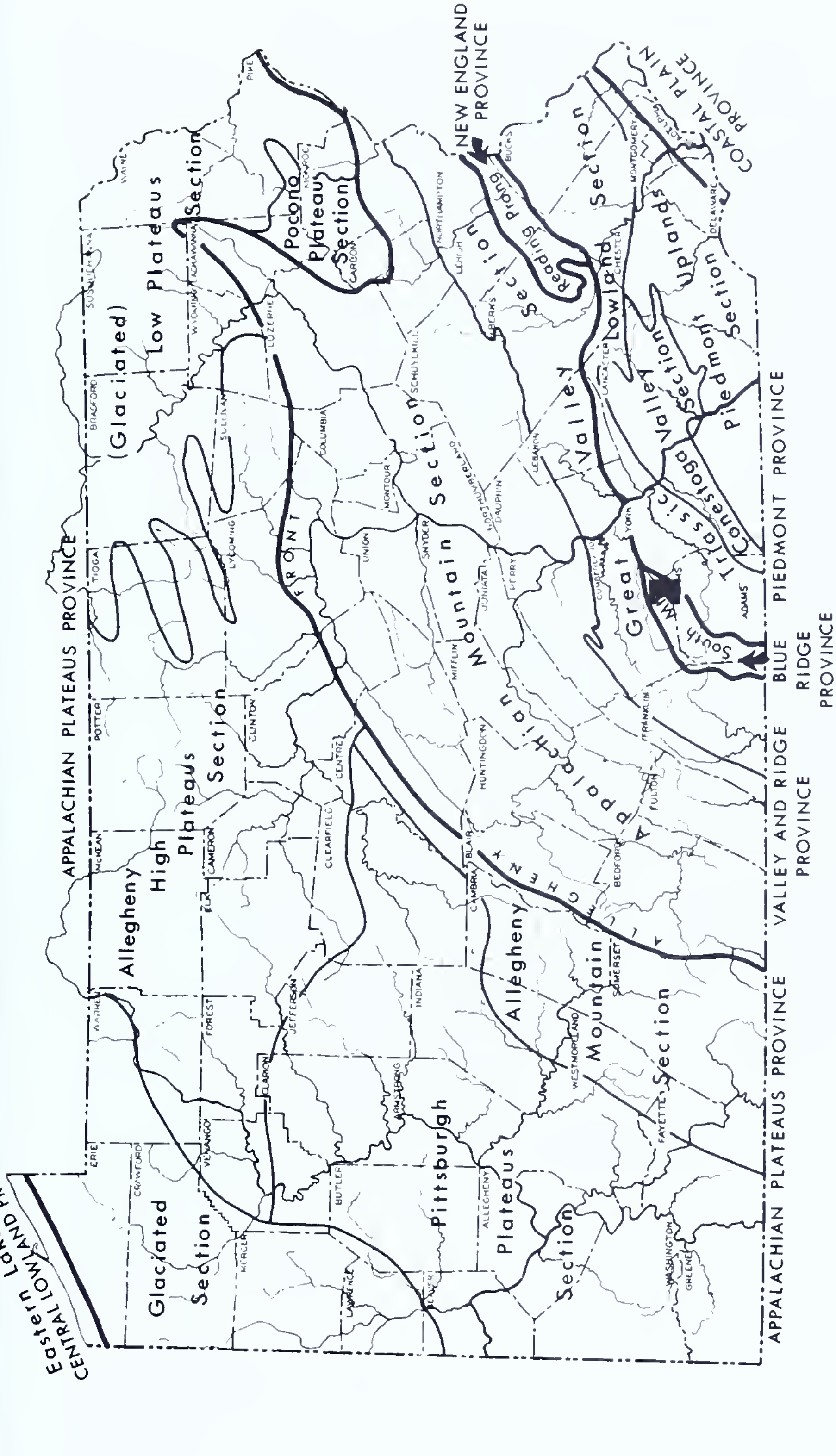

Figure 1. Location of the Mt. Holly Springs 7½-minute quadrangle.

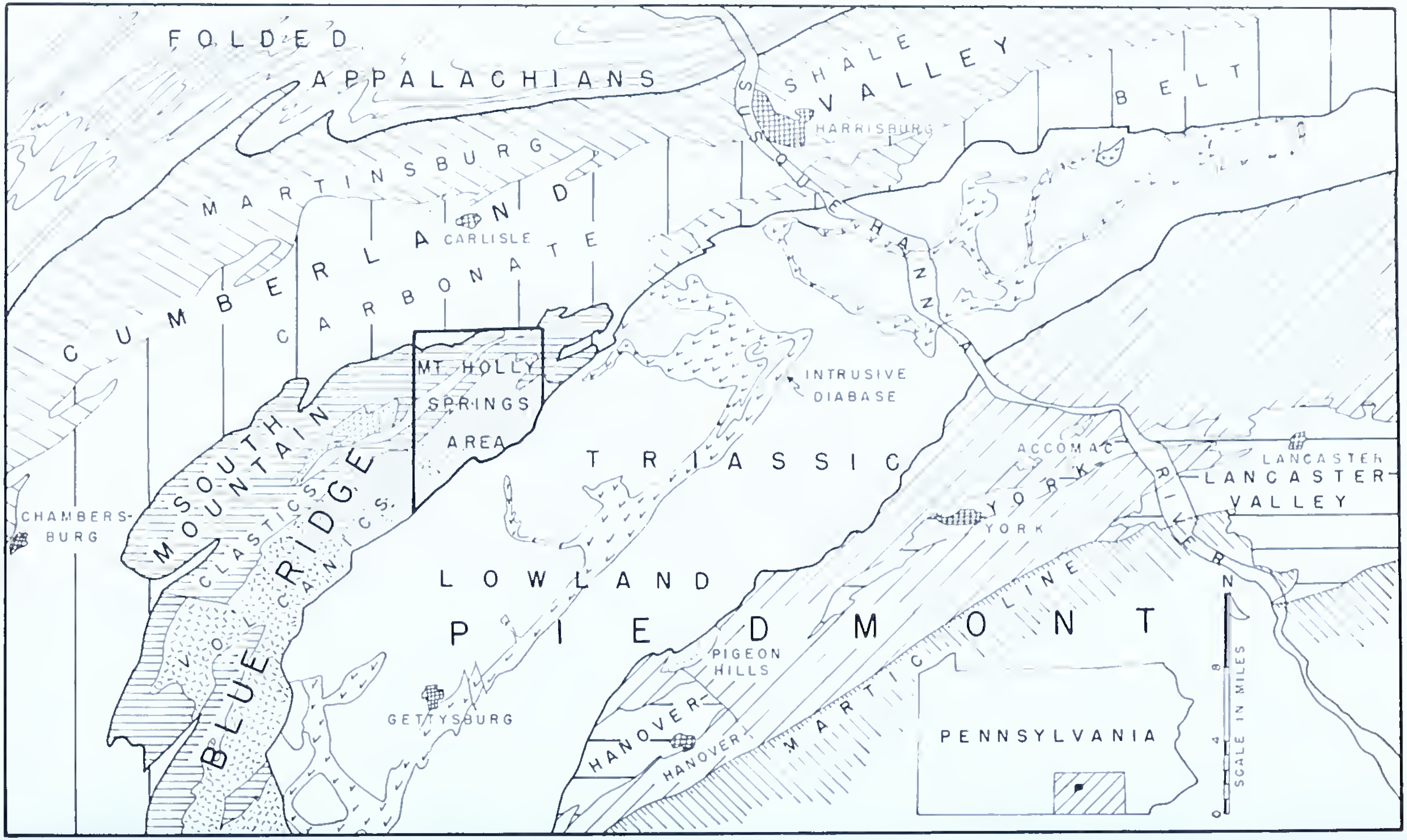

Figure 2. Regional geologic setting of the Mt. Holly Springs area.

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Dr. Carlyle Gray, former director of the Pennsylvania Geologic Survey and Dr. Arthur Socolow, the present director, introduced the author to the Mount Holly Springs area. Numerous subsequent discussions have been most helpful. Richard R. Conlin and Donald M. Hoskins, geologists with the Pennsylvania Geologic Survey, each spent two full days in the field and contributed in critical discussions. Professor D. U. Wise, Franklin and Marshall College, and R. D. Bentley, Georgia Geologic Survey, visited key areas and discussed problems most helpfully. Student assistants worked in the field at all stages of the work: H. Lawrence McKague, during the summers of 1958 and 1959; Michael Forth, during the summer of 1960 and for short periods at other times; John Ronald Houpt, for a week; and Michael Jaron, for a few days. The manuscript has benefitted by critical suggestions from Alan Geyer, Sam Root, and D. M. Lapham of the Pennsylvania Geological Survey.

GENERAL GEOLOGY

PREVIOUS WORK IN THE MOUNT HOLLY SPRINGS AND RELATED AREAS

Henry D. Rogers (1858) of the First Pennsylvania Survey and Persifor Frazer of the Second Geologic Survey mapped the rocks in the Mount Holly Springs quadrangle. Bascom (1896) in her work on volcanic rocks of South Mountain studied rocks similar to some in this report. The problem of the age of the Catoctin volcanics, the relationship of the Loudoun and Swift Run Formations to the Chilhowee Group and the boundary between the Cambrian and Precambrian were argued by Geiger and Keith (1891), Keith (1891 and 1923), Stose (1909), Barrell (1925), Jonas and Stose (1939), Stose and Stose (1946 and 1949), Bloomer and Bloomer (1947), King (1949), Whitaker (1955), and King, Hadley, Neuman and Hamilton (1958). Cloos (1940, 1947 and 1950) utilized structure to help solve stratigraphic problems in the Blue Ridge and Great Valley although not specifically in the Mount Holly Springs area. Reed (1955) found a varied topography on which the Catoctin Formation had been extruded. Nickelsen (1956) subdivided the Loudoun into two members and the Weverton into three distinctive quartzite members in the Blue Ridge near Harpers Ferry. Stose and Bascom (1929) mapped the Fairfield and Gettysburg (15′) quadrangles south and southwest of the Mount Holly Springs (7½′) quadrangle. Stose (1907a, 1907b and 1910) referred to economic deposits of white clay, phosphate ores and copper deposits of South Mountain. Foose (1945) described the manganese minerals and deposits at White Rocks, Cumberland County in the southwestern part of the Mechanicsburg and the northwestern part of the Dillsburg (7½′) quadrangles. These quadrangles abut the Mount Holly Springs quadrangle to the northeast and east respectively.

PROBLEMS

It is a measure of the complexity of the geology and possibly of the scarcity of outcrop that despite all the able work done on the Lower Cambrian and Precambrian of the Blue Ridge province, important problems still remain to be solved. The major question in the Mount Holly Springs quadrangle is whether South Mountain is an anticlinal uplift or an overthrust block. Subsidiary to this question is the relationship of the Catoctin volcanics to the overlying clastics. Was there a significant time lapse between volcanic flows and clastic deposition? Were the volcanics folded prior to clastic deposition or have all been involved in one or more deformations? Are the volcanics Cambrian or Precambrian?

Numerous minor problems became obvious early in the study:

1. Is the complex gneissic basement floor of the Catoctin volcanics exposed in the area?
2. Is there a Loudoun Formation as postulated by Stose; and if so, of what rock units is it constituted?
3. If there is no Loudoun Formation, what is the nature of the volcanic rock-Weverton contact: conformable, unconformable, fault?
4. Is there any distinction between the Antietam Quartzite and the Montalto Quartzite which Stose described in identical terms?
5. Is the Harpers Phyllite present or absent?
6. Is there fossil evidence for the ages of the clastic rocks?
7. What are the structural relations in all the rocks?

Not all of these problems have been answered definitively in the present study.

GENERAL STATEMENT

The Blue Ridge province in the Mount Holly Springs quadrangle is underlain by metamorphosed Precambrian (?) volcanics and Cambrian clastics and carbonates. The mountainous areas to the northwest are underlain by the following formations from oldest to youngest: Loudoun Formation, Weverton Quartzite, Harpers Formation and its Montalto Quartzite Member, and Antietam Quartzite. These are overturned to the northwest in folds which plunge gently northeastward and are locally faulted against the younger Tomstown Dolomite and the older volcanics. Mount Holly, Keller Hill, Trench Hill, Trent Hill, Piney Mountain, Rocky Ridge and The Peak are underlain by one or more of these formations (Plate 1).

The metavolcanic rocks and interlayered clastic metasedimentary rocks are in the foothills southeast of Piney Mountain, Trent Hill and Trench Hill. These are mildly metamorphosed basalts, rhyolites, possibly tuffs and kaolinitic siltstones and kaolinite which have been flow-folded into irregular but generally northeast-trending bands. These have been altered to metabasalts (greenstones), aporhyolite porphyry, aporhyolite, muscovitic quartzite, and muscovitic phyllite.

The intermontane valleys underlain by Tomstown Dolomite, which also lies conformably on the Antietam Quartzite on much of the northwest flank of South Mountain, are either downfolded, downfaulted, or overridden. Quaternary alluvium filling the stream valleys has not been mapped in this study (Plate 1).

STRATIGRAPHY AND PETROGRAPHY

INTRODUCTION

Several factors complicate the mapping of the metavolcanic and metasedimentary rocks. The first factor, which is typical of the whole area, is the dearth of outcrops. The chief complication is the almost complete lack of traceable marker units which could be utilized to determine stratigraphy and structure. Problems present here but which are not normally encountered in simple volcanic rocks are:

1. very complex structures;
2. many similar discontinuous units;
3. probable irregular initial dips; and
4. regional metamorphism.

The metavolcanic rocks in the Mount Holly Springs quadrangle can be correlated with the Catoctin Formation (Table 1), because they occur in the same stratigraphic horizon and are similar in occurrence, mineralogy, and petrology. Geiger and Keith (1891) named them the Catoctin Schist because they represent a distinctive unit below the Lower Cambrian clastics (Chilhowee Group) as described by Jonas and Stose (1939), Stose and Stose (1946), Bloomer and Bloomer (1947), and King (1949). The volcanic rocks were termed metabasalt and aporhyolite by Bascom (1896); the first prefix, meta-, refers to any change a rock might undergo; the second prefix, apo-, refers to a special change, in this case, devitrification. Bloomer and Bloomer (1947) called the metabasalt

Table 1.—*Correlation chart with areas in Virginia and Tennessee.*

Adapted from King (1949, p. 519) and Nickelsen (1956, p. 242)

	East-central Tennessee (Chilhowee Mountain)		*Northeastern Tennessee* (Johnson, Carter and Unicoi Counties)	*Northern Virginia* (Elkton and Harpers Ferry areas)	*Mount Holly Springs, Pa.*
Lower Cambrian	Shady Dolomite (in Miller Cove)		Shady Dolomite	Tomstown Dolomite	Tomstown Dolomite
	Hesse Quartzite	Chilhowee Group	Erwin Quartzite	Antietam Quartzite	Antietam Quartzite
	Murray Shale				
	Nebo Quartzite				
	Nichols Shale		Hampton Shale	Harpers Shale	Harpers Formation
	Cochran Conglomerate		Unicoi Formation (with basalt flows) 1000-1500 feet below top)	Weverton Quartzite Loudoun Formation (With tuffaceous slate and rare flows)	Weverton Formation Loudoun Formation
Precambrian	Ocoee Series		Volcanics of Mt. Rodgers area	Catoctin Greenstone Swift Run Formation	Aporhyolite Metabasalt
			Cranberry Granite	Injection complex	

"propylite" or altered andesite. Stose (1953) indicated a dominance of rhyolitic rocks in the Carlisle (15′) quadrangle—"traversed by bands of sericite slate and greenstone schist—."

In this investigation it was possible to subdivide the metavolcanic rocks into metabasalt (greenstone), aporhyolite, aporhyolite porphyry, lavender aporhyolite, and the associated sedimentary rocks into muscovitic quartzite and muscovitic phyllite.

Bascom (1896) found evidence that the aporhyolite underlies the greenstone (metabasalt). The opposite is apparently true in the Mount Holly Springs quadrangle.

METABASALT

Metabasalt occurs in two connected northeast-trending bands in Huntington and Latimore Townships, in one small patch in each of the two townships, and interlayered with aporhyolite in Menallen Township. The only extensive exposures of metabasalt crop out on the west slope of Fickels Hill in Latimore Township. Here, a series of en echelon elongate outcrops, each 15 to 100 feet long and 10 to 15 feet across, extend up the hill. This sequence of basaltic lava flows is now altered to many shades of green and gray chloritic schists. "The shade of green which the rock exhibits depends on the dominant alteration product: epidote, commonest alteration mineral, gives a light yellowish-green color, chlorite and actinolite give a darker green, and a mixture of the three gives intermediate shades. The purple and grey varieties owe their colors to iron oxide and to relative scarcity of ferromagnesian alteration products." (Stose and Bascom, 1929, p. 5). The only primary structures observed in these rocks are amygdules. No pillow lavas, columnar jointing or flow layering were seen. Rocks are massive to well cleaved, aphanitic to fine- to coarse-grained, porphyritic or amygdaloidal. Locally black phyllite (possibly metasedimentary) is interlayered with metabasalt, and numerous massive, fine-grained, light-green to olive-green lenses and pods of epidotized rock parallel to flow foliation (S_1) or the slip or fracture cleavage (S_2) (Plate 1). Epidotized rock is almost invariably associated with milky quartz veins, pods or disseminations. It consists dominantly of fine-grained, pale-green to olive-green quartz-epidote rock with numerous pyrite cubes which weather to produce a limonitic surface.

Most of the exposed metabasalts are cleaved, dark-green rocks composed of chlorite, epidote, uralitic actinolite, plagioclase, sericite, sphene, magnetite and quartz. Locally thin veinlets of pink piemontite cross the dark-green groundmass. Thin sections of metabasalt demonstrate a predominant flow cleavage in which most of the micaceous and fibrous minerals have become well oriented. Chlorite in small flakes and shreds, with maximum grain size of 0.30 mm, is pale green in plain light and anomalous light brown to purple in polarized light. The gamma index of 1.627, an alpha index of 1.625, the negative sign, and a birefringence of 0.002 indicate ripidolite with 2.75 Si, 2.87 total Fe, and 0.55 $\frac{\text{Fe total}}{\text{Fe}+\text{Mg}}$ (Deer, Howie and Zussman, 1962, v. 3, p. 151). Epidote occurs as individual grains and scattered clusters ranging from .075 to 0.60 mm in diameter. With 2V of 88° and beta index of 1.742, the epidote contains 18 percent of the $HCaFe_3Al_3Si_3O_{13}$ molecule (Winchell and Winchell, 1951). Porphyroblasts of fibrous uralitic actinolite are probably an alteration of original pyroxene or hornblende of the basalt flows. In one thin section (JF-393-60) a leached, epidotized orthorhombic amphibole, faintly pleochroic in white and olive green, is probably relict. Minerals termed amphibole in the field were identified as uralitic actinolite coated with manganese oxide (Fig. 3). Plagioclase (An_{8-12}, determined by oil immersion in white light) occurs as saussuritized phenocrysts and interstitial, oriented grains parallel to flow cleavage in the matrix. Plagioclase has been partly albitized from an original labradorite (?). The maximum diameter of plagioclase porphyroblasts is 2.25 mm. Interstitial grains range in diameter from 0.015 to 0.075 mm. Sericite occurs as flakes and shreds altering plagioclase. Masses of cryptocrystalline

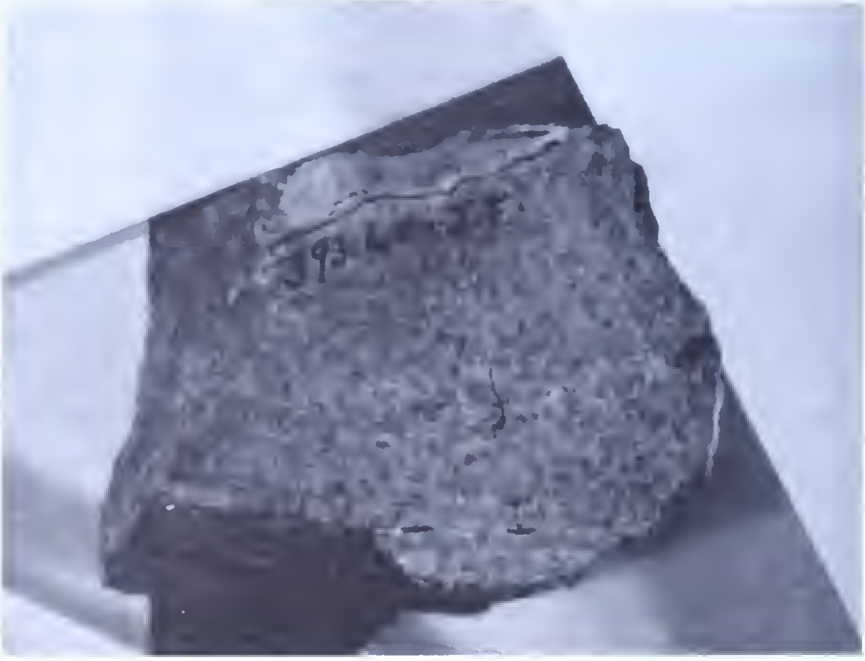


Figure 3. Metabasalt with porphyroblasts of uralite-actinolite from hill 4000 feet northeast of Snyders Hill.

aggregate (possibly original rutile) are altered to leucoxene. Magnetite is scattered uniformly throughout some metabasalt as subhedral to anhedral grains from 0.0075 to 0.225 mm in diameter but is locally concentrated around amygdules. A few rocks contain enough magnetite to attract an Alnico magnet. Quartz occurs mostly as veins, vesicle fillings and injections along the more permeable tops of flows. Contacts of quartz and metabasalt are marked by a rim of single grains of epidote. Locally the central part of an amygdule contains calcite, as the last filled portion of the vesicle. In epidotized rock, called epidosite by Reed (1955), the quartz grains are uniformly distributed.

Only two outcrops of amygdaloidal metabasalt (Fig. 4) were observed, one on the west slope of Fickels Hill (Fig. 5) and the other southwest of the house at the intersection of State Route 94 and the east-west road to Uriah and Myerstown. Because amygdaloidal layers typically form at the top of lava flows, this represents one of two ways to recognize top and bottom contacts between flows. These amygdules seems to indicate that the flows are right side up and that layers are dipping uniformly southeastward. The amygdules of epidote, quartz, and chlorite, surrounded by concentrations of magnetite grains, are flattened in the cleavage planes and locally oriented down the cleavage dip. S_1 cleavage planes wrap around and S_2 cut across amygdules.

Black phyllite or slate is interlayered locally with the metabasalt and

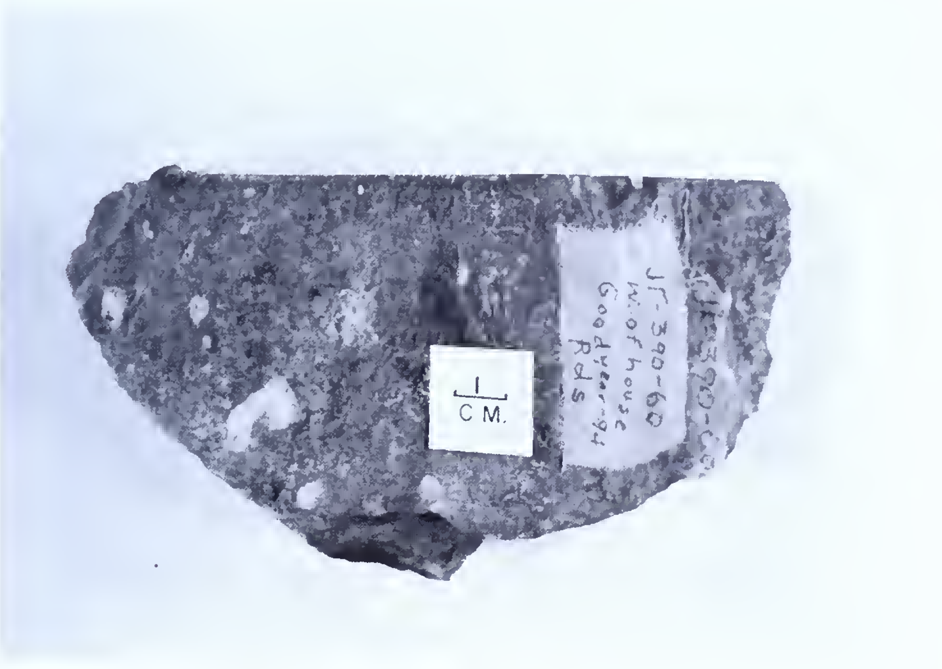


Figure 4. Dark-greenish-gray amygdaloidal metabasalt. Amygdules are quartz with a thin rim of epidote at the contact. Matrix consists of chlorite, albite and epidote.

may have been a mafic tuffaceous deposit, a soil, or a fine-grained sedimentary rock. Any of these origins would represent a break in the continuity of lava flows and provides evidence for the thickness of the flows. On the west slope of Fickels Hill, outcrops near the top of the hill indicate a thickness of 3 to 10 feet. If thickness of flows can be construed from width of outcrop, the flows ranged from a few feet to 20 feet thick. Estimation of the thickness of the metabasalt in the Mount Holly Springs quadrangle depends on structural interpretations. If each of the bands and patches shown on Plate 1 is a separate series of lava flows dipping an average of 45° SE, the thickness of the total would be about 3,000 feet. Reed (1955, p. 881-883) at Luray, Virginia, found seven lava flows with an average thickness of 215 feet and a maximum thickness of 1,800 feet. Stose and Bascom (1929, p. 23) estimate the thickness of the metabasalt at 500± feet in the Pigeon Hills and 1,000+ feet at South Mountain in the Fairfield-Gettysburg areas. It seems unlikely that there would be 3,000 feet of metabasalt in the Mount Holly Springs quadrangle near the northeasternmost extremity of exposures of volcanic rocks where they would be expected to be thinnest in the Blue Ridge province. An alternative interpretation of the bands and patches as part of a folded sequence of lava flows is more probable. This would reduce the total thickness and is based on evidence for folding in the overlying aporhyolite and Cambrian sedimentary rocks. In Plate 1, the assumption is made that

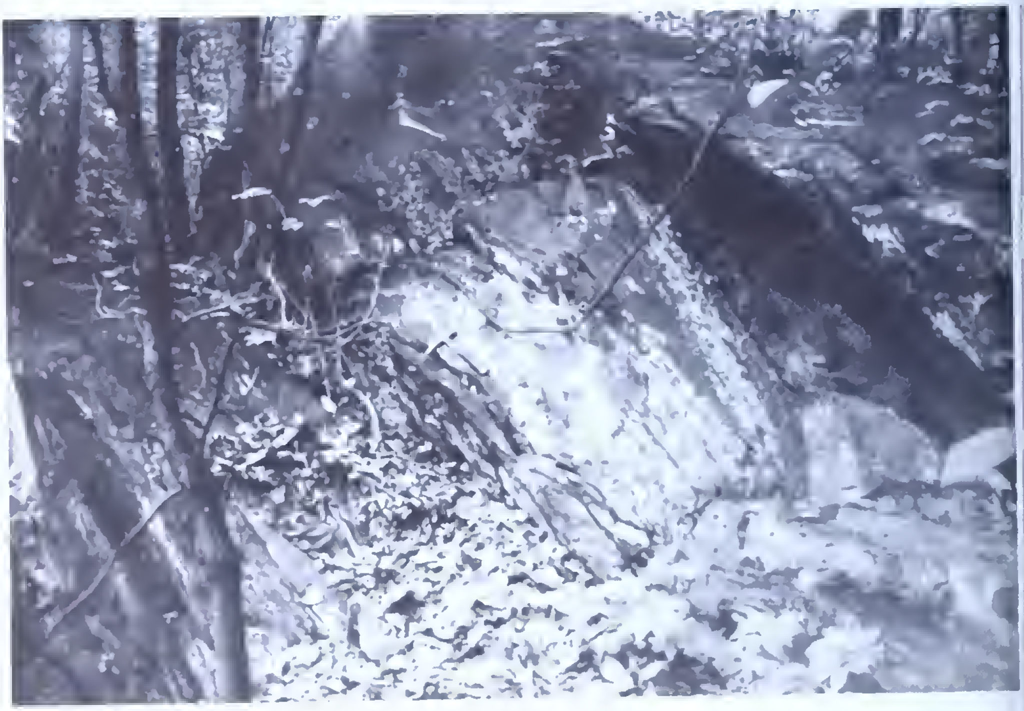


Figure 5. Outcrop of metabasalt interlayered with metasedimentary rock on Fickels Hill, showing cleavage dipping 45 SE.

each band of metabasalt represents a fold; e.g. one limb dipping an average of 45° would indicate a thickness of 550 feet. Evidence for folding will be presented later in this report under "Structural Geology."

A sheared, massive, black, coarse-grained gabbro which may be in the form of a thick dike crops out on State Route 94 east of Snyders Hill. Because the rock has undergone considerable deformation and is similar in composition to the metabasalt, it may be genetically related to the basalt flows of the area. East of State Route 94, on the northwest slope of hill 1105, are boulders of metabasalt, which also may be related to the flows.

RHYOLITIC ROCKS

Aporhyolite

Aporhyolite occurs in a continuous strip about 8 miles long and a maximum of 1½ miles wide, from the southwest corner in Menallen Township northeastward across Huntington and Latimore Townships and into Franklin Township in York County. The boundaries of the aporhyolite are irregular against metabasalt, aporhyolite porphyry, muscovitic quartzite and muscovitic phyllite.

There are a few significant outcrops of aporhyolite: north and south of the crest of Big Hill in the Biglerville (7½′) quadrangle to the south, are extensive outcrops of gray nonporphyritic and porphyritic massive to well-cleaved aporhyolite with well-developed S_1 flow layering (Fig. 6); north of the north peak of Fickels Hill in Latimore Township is a long outcrop of gray massive aporhyolite with a few pink feldspar phenocrysts and well-developed S_1 flow layers of pink and gray aporhyolite (Fig. 7); the ridge east of the peak of Fickels Hill is underlain in part by laminated, gray, massive, flow-layered aporhyolite. Most aporhyolite is similar and all weather to a light gray.

In thin section quartz occurs in lenticular grain clusters which are elongate parallel to the flow layers. Alternate layers (2 to 5 mm thick) of very fine-grained albite (maximum diameter 0.015 mm) and coarser grained quartz (maximum diameter 0.225 mm) are aligned. Imbedded in them are fine to coarse grains of magnetite, hematite after magnetite and ilmenite altered to leucoxene. Locally less recrystallized parts of the specimens contain distorted spherulites The latter were too fine grained for any optical determinations but are presumably composed of sanidine and quartz.

No textures or structures were observed which could give any indication of tops or bottoms of rhyolite flows or the thickness of individual flows. The flattened grains are similar to those in ignimbrites, but are more likely the result of recrystallization during metamorphism. Some of the aporhyolite may have been formed as *nueés ardentes.*

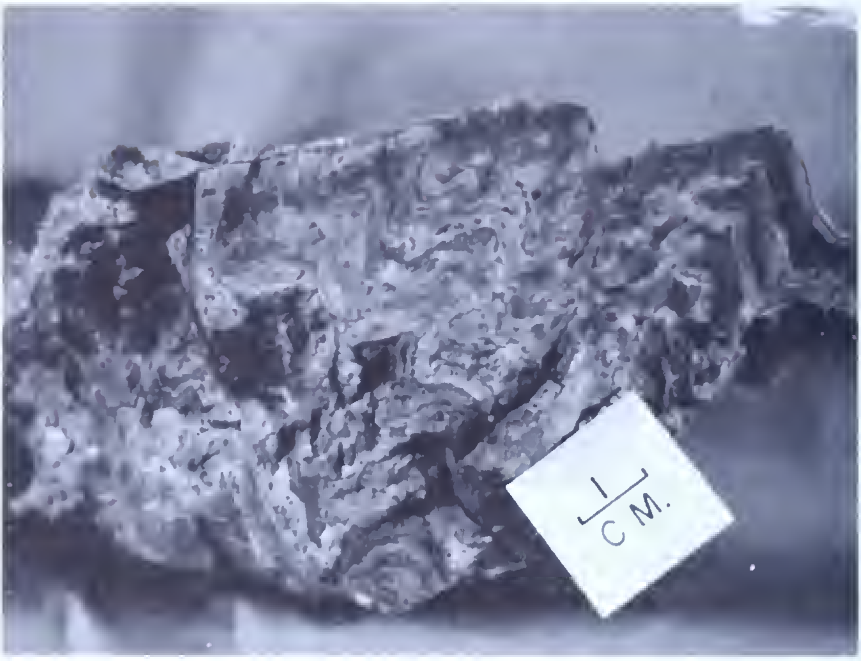


Figure 6. Hand specimen of highly folded, thin-layered, light- and dark-gray aporhyolite porphyry with pink feldspar phenocrysts that disrupt the flow layers. From Big Hill just south of south edge of map in Biglerville quadrangle.

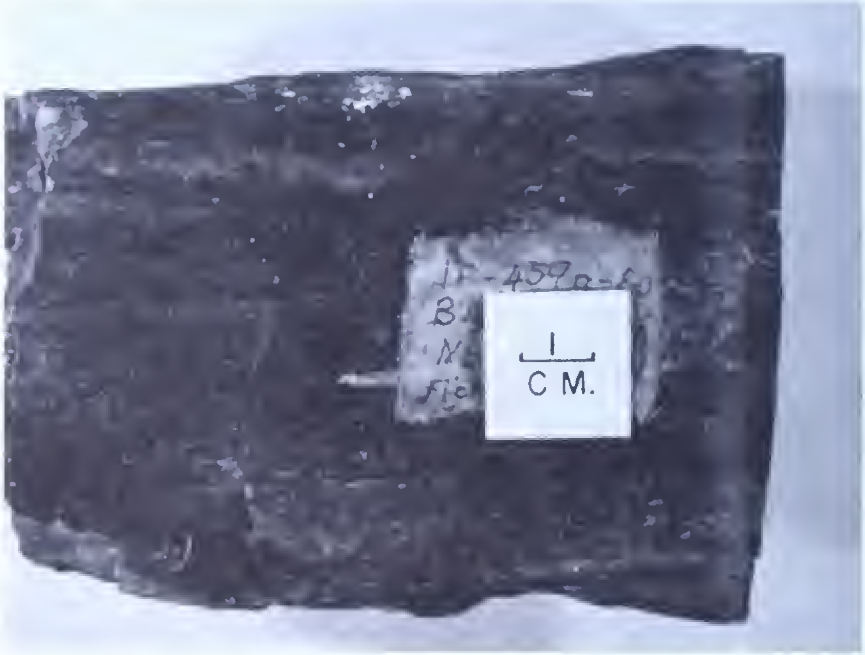


Figure 7. Hand specimen from large en echelon outcrops north of north peak of Fickels Hill. Dark-gray and pink strongly flowbanded aporhyolite.

The maximum width of the aporhyolite area represents its interpretation as a single fold. The thickness, assuming an average dip of 45° would be about 2,000 feet. There are indications of reversals of dip (road to Mt. Tabor east of Big Hill, near the south edge of the map) which would reduce the thickness. There is little information about the extent of folding and therefore about the true thickness. There may be as much as 2,000 feet of aporhyolite in the Mount Holly Springs quadrangle, but maximum thickness determined from the cross sections is 600 feet (Plate 1).

Aporhyolite Porphyry

Aporhyolite porphyry occurs in a number of small bands elongate northeast-southwest and two large bands in Tyrone, Huntington, Dickinson and South Middleton Townships. Based on the evidence of float and a few outcrops, the smaller bands are not entirely aporhyolite porphyry but probably are interlayered with the aporhyolite and lavender aporhyolite surrounding them.

A variety of different-appearing rock types are included in the aporhyolite porphyry. They have in common blastoporphyritic texture and relict phenocrysts of quartz and/or feldspar. It seems unlikely that these represent one lava flow but the author was unable to distinguish separate flows or correlate outcrops and float by subdivision into distinct subunits. The inference is that there was probably more than one flow (Fig. 8) possibly derived from a single magma and having different cooling histories.

A few types of aporhyolite porphyry have been observed: 1. About one-half mile southwest of Goodyear (Fig. 9) and on the ridge about one-half mile north of Myerstown (Fig. 7) there are outcrops of dark-gray, massive, faintly-cleaved rock with dark-gray, small (1-2 mm) phenocrysts of quartz and abundant, striking, pink subhedral to euhedral crystals of feldspar. Some of the larger feldspar grains (5 mm) have cores of quartz which suggest secondary growth. Phenocrysts generally have their intermediate dimension in tectonic "b" and the long dimension in "a." 2. Quite different looking are two finer grained rocks, one from a gutter outcrop on the road west of Idaville (north of the "u" in Bermudian, Plate 1), and the other from the road east of Starners. They are light-gray, massive, faintly foliated rocks with aphanitic light- to darker-gray matrix and white, pale-pink or pale-olive anhedral feldspar and dark-gray quartz relict phenocrysts. The relict phenocrysts are oriented similarly but less uniformly. 3. One of the most striking types of aporhyolite porphyry was collected on the south ridge of Big Hill in Menallen Township in the northwest corner of the Biglerville (7½′) quadrangle. This is a rock with thin (2-3 mm) light-gray and black

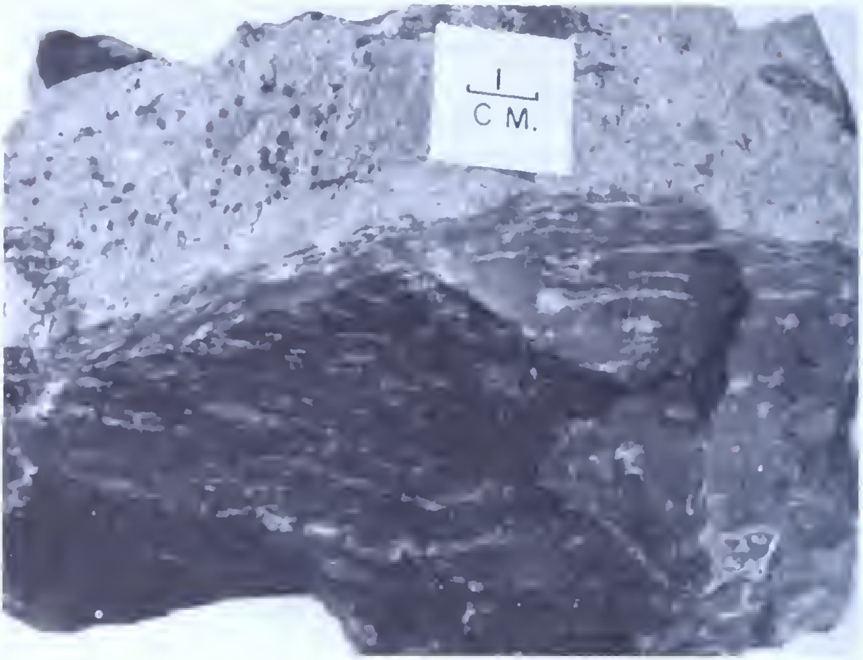


Figure 8. Contact between dark-gray, flow-layered and massive light-gray aporhyolite. The dark-gray rock has numerous scaly inclusions of the light gray.

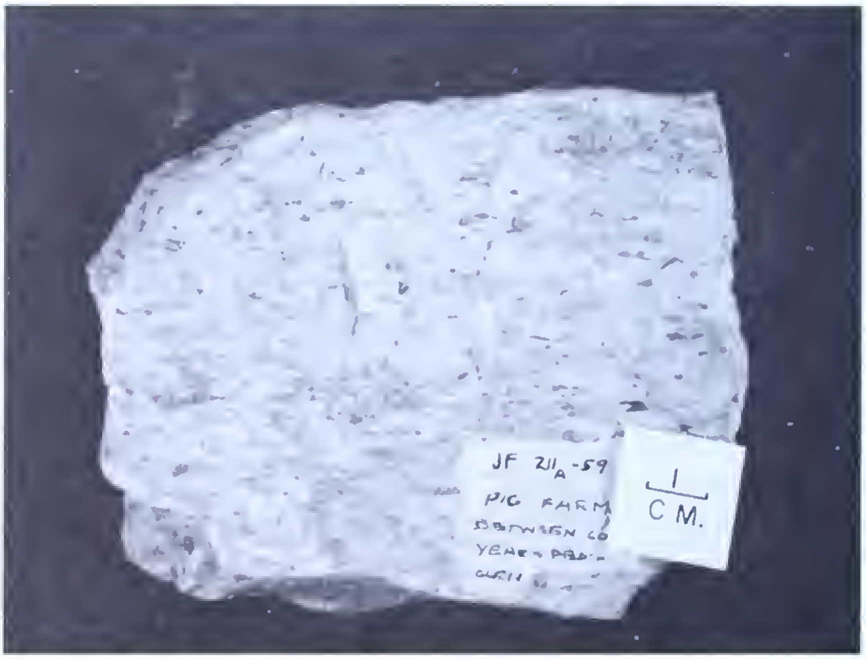


Figure 9. Hand specimen of light-gray aporhyolite with subhedral pink feldspar and gray quartz phenocrysts oriented in tectonic "a", from pig farm 2200 feet southwest of Goodyear.

alternating layers which were tightly folded with a wave length of one centimeter. These folds were disturbed by later growth of pink feldspar porphyroblasts about 2 mm in diameter (Fig. 6). 4. Another common type is similar to a specimen taken from the southwest corner of the road intersections at Goodyear. This has a light-gray aphanitic matrix which is faintly foliated with oriented relict phenocrysts of lenticular to rounded dark-gray quartz and larger grains of pink, rounded potash feldspar. The rock may have been a welded tuff or a divitrified glass. Most grains are elongate in "a." The rounded grains of quartz and feldspar may indicate rolling during or after consolidation. 5. Locally abundantly blastoporphyritic rocks contain more muscovite than most aporhyolite porphyry and consequently were sheared more intensively. Representative specimens were collected from Chestnut Ridge School west of Cold Spring Run Road in Dickinson (7½′) quadrangle and on the road north of Myerstown. They are light-gray to pale-pinkish-gray, strongly cleaved rocks with white or pink and white, rounded to lenticular feldspar aggregates with smaller dark-gray quartz relict phenocrysts. The feldspar phenocrysts range to 10 mm in length and typically are elongate in "a."

Lavender Aporhyolite

Lavender aporhyolite and aporhyolite porphyry differ little from gray aporhyolite and porphyry. Principally they differ in color which seems to be caused by the oxidation state of the iron oxides. Gray rocks typically have magnetite and ilmenite and lavender rocks have hematite and ilmenite. The question arises as to whether lavender rocks should be mapped as a distinctive unit or correlated with gray aporhyolites. Both types of rhyolite occur as one long narrow belt, southeast of the muscovitic phyllite at the foot of Piney Mountain and southeast of the Weverton Quartzite to the northeast, and in a large patch between Rocky Ridge and The Peak. Because the lavender rocks make distinctive units, they have been mapped separately. The most prominent outcrops of lavender aporhyolite are exposed on the hill across the road and southeast of Pine School in the Rocky Ridge syncline (Plate 1).

The lavender aporhyolite ranges in color from brownish pink to pale lavender, deep lavender and dark purple. It invariably has an aphanitic matrix and irregularly distributed phenocrysts of both quartz and feldspar. The extent of cleavage is variable. Locally there are flow layers of very fine-grained matrix quartz and oriented relict phenocrysts of quartz and feldspar.

Two thin sections of lavender aporhyolite were studied. One, from 3,400 feet north of Goodyear on the old road to Hunters Run, is a massive, lavender rock with fine, wavy cleavage and very fine-grained quartz and feldspar relict phenocrysts. The second, from 3,200 feet north of Mt. Victory Church on Route 91, is massive, pale lavender and flow layered (1-3 mm thick) with subhedral relict phenocrysts of pink feldspar and rolled rounded grains of quartz. The matrix of both consists of very fine grains of quartz (0.0032 to 0.032 mm in diameter) and possibly some sanidine. In the former, the fine-grained relict phenocrysts (0.0150-0.150 mm) are quartz and oligoclase (An$_{12-15}$). The feldspar composition was determined by the extinction angles of albite twinning in thin section. A few partial and distorted spherulites are relict and indicate devitrification. A few magnetite grains considerably altered to hematite occur as disseminations. Larger hematite grains and ilmenite altered to leucoxene are accessory minerals. In the second thin section, the relict phenocrysts are braided antiperthite ranging to 3.15 mm in diameter with rounded grains of quartz which typically show strong undulatory extinction (the classification of perthites is from Deer, Howie, and Zussman, 1963, p. 68). A few contain plagioclase nuclei. One antiperthite relict phenocryst has a moth-eaten appearance with quartz in the holes, suggesting incomplete separation of silica and extremely rapid cooling.

The principal structures are flow layering and variable cleavage. It takes close observation to see that the relict phenocrysts are oriented. Within the boundaries of lavender aporhyolites other rock types are present. East of Pine School there is a patch of gray aporhyolite porphyry which has small amounts of lavender rocks within its boundaries, just as the areas indicated as having only lavender rocks contain local layers of aporhyolite, aporhyolite porphyry, muscovitic quartzite and muscovitic phyllite. Lavender rocks are the dominant rocks in the areas indicated. The thickness of lavender aporhyolite is estimated to be about 500 feet.

LOUDOUN FORMATION

Nickelsen (1956, p. 217), reviewed the origin and history of use of the term Loudoun Formation. Because it is necessary to compare this with Stose's usage of the Loudoun Formation in the Mount Holly Springs quadrangle, Nickelsen's review follows:

> The Loudoun formation was named by Keith (1892, p. 365; 1893, p. 321; 1894) who indicated only Loudoun County, Virginia, as the type locality. Stose and Stose (1946, p. 19) recognized both the Swift Run Formation and Loudoum Formation in Loudoun County and adjacent Maryland and showed that many of Keith's "Loudoun" localities actually were the lithologically similar Swift Run Formation. Some of the Loudoum of this area, as restricted by Stose and Stose, was later shown to be lower Harpers Formation by Cloos (1951, p. 29). This led Cloos to question the validity of the Loudoun as a unit. King (1950, p. 9, 16) recognized the Loudoun and Swift Run Formation near

Elkton, Virginia, but due to the above ambiguities in definition, questioned whether the "Loudoun" was a valid name (1950, p. 16). The writer found both the Swift Run Formation and Loudoun Formation present in Loudoun County, Virginia, and thinks that the name Loudoun should be retained in the original sense of Keith for characteristic beds occurring between the Catoctin volcanics and the Weverton quartzite.

G. W. Stose (1953) described the Loudoun Formation in the Carlisle (15′) quadrangle as follows: "The basal [metasedimentary] unit, or Loudoun formation, is a coarse, poorly sorted, poorly cemented deposit, made up of detritus derived from the erosion of the underlying volcanic rocks and of deeply weathered granitic rocks—." In the Fairfield-Gettysburg Folio (1929) and "The Geology and Mineral Resources of Adams County" (1932) Stose indicated that the soft, sericitic schistose lavender rock constituted the lower member and conglomeratic rock with quartz and purple rhyolite fragments, the upper member. He also stated that the Loudoun Formation underlay the lower areas whereas Weverton Quartzite made up the hills. In the Chambersburg-Mercersburg Folio (1909) there was too little Loudoun Formation to differentiate as a unit. In the present study, Weverton Quartzite was found in both hills and valleys.

Because deposits on top of the volcanic rocks and underlying the Chilhowee Group or Lower Cambrian clastics have been the traditional requirements for the Loudoun Formation, muscovitic quartzite and muscovitic phyllite mapped in this interval are defined as the Loudoun Formation in this area. Only Stose's lower member will be referred to the Loudoun Formation. The lithology designated by Stose as the upper member was observed locally but was not mappable and was included for mapping purposes with the Weverton Formation.

Muscovitic Quartzite

Three small areas (Plate 1) are underlain dominantly by muscovitic quartzite or quartz-muscovite phyllite. Many rocks in the Mount Holly Springs area are foliated and schistose. Most of those designated muscovitic quartzite show distinct planes of muscovite but not sufficient to be classified as muscovitic phyllite which is dominantly muscovite. Good exposures of muscovitic quartzite occur on the low southwest extension of Rocky Ridge and the hill southeast of it.

Stephenson (1950) identified the micaceous mineral in muscovite phyllites and quartzites as pyrophyllite ($Al_2Si_4O_{10}[OH]_2$) on the basis of a chemical test which indicated aluminum rather than the magnesium expected in talc ($Mg_3Si_4O_{10}[OH]_2$). D. H. Lapham (personal communication) using X-ray diffraction determined that at least some of it is muscovite.

Muscovitic quartzite has a microgneissic structure of thin lenticular layers (1-3 mm thick) of white to light-gray, very fine-grained quartzite separated by very thin layers of muscovitic phyllite. Locally, as at the intersection of Route 91 and the road south of Fickels Hill, rounded grains of quartz with cataclastic texture create a bumpy surface on the quartzite. The muscovitic quartzite is highly folded so that an estimate of its thickness is not very reliable. It may be about 500 feet at its thickest and range down to zero.

Muscovitic Phyllite

Muscovitic phyllite occurs in four small pods and a long narrow strip (Plate 1). The pods extend up to 3,000 feet long and 1,000 feet wide. The best exposures of muscovitic phyllite occur at the Gargol pits and northwest of Goodyear (referred to as the Goodyear pit). There are good natural exposures southeast of Rockeys School.

In hand specimen muscovitic phyllite is light gray to colorless or white, pale green and shades of lavender, strongly foliated and folded, locally limonite-stained and composed dominantly of muscovite and pyrophyllite. At the Gargol pit, in chlorite schist and muscovitic phyllite, porphyroblasts of chloritoid (Figs. 10 and 11) attain a maximum of 5 mm in diameter. Some of the muscovite phyllite contains grains of quartz and is gradational in composition with muscovitic quartzite with some lenticular, layered chert. In contact with the muscovitic phyllite there are layers of metavolcanic and layered metasedimentary rocks (Fig. 12) which mark bedding (S_0). Folding has developed several sequences of flow cleavages, S_1, S_2, and S_3 and axial planes of folds essentially parallel to them (Plate 2, Fig. 5) with lineations $L_{1\times2}$, $L_{2\times3}$ and axes A_1, and A_2.

In thin section, muscovite phyllite is characterized by elongated flakes and shreds of muscovite oriented in planes that show chevron folds and crinkles. Flakes range in size from 0.025 to 0.5 mm. Where quartz is present, it is intergranular with muscovite which wraps around it. Larger grain aggregates have a cataclastic texture. Stretched quartz is generally oriented parallel to S_1. In one specimen from the Gargol pit, lenses of ditrital glass with microcrystalline quartz, feldspar and/or muscovite indicate a volcanic origin for a part of the sediment. Euhedral crystals of magnetite and numerous scattered grains of hematite locally altered to limonite are accessory. The latter produces the lavender color in some of the muscovite phyllite. Most of the muscovite is translucent and pale green. The thickness of the muscovite phyllite is probably only 100 or 200 feet.

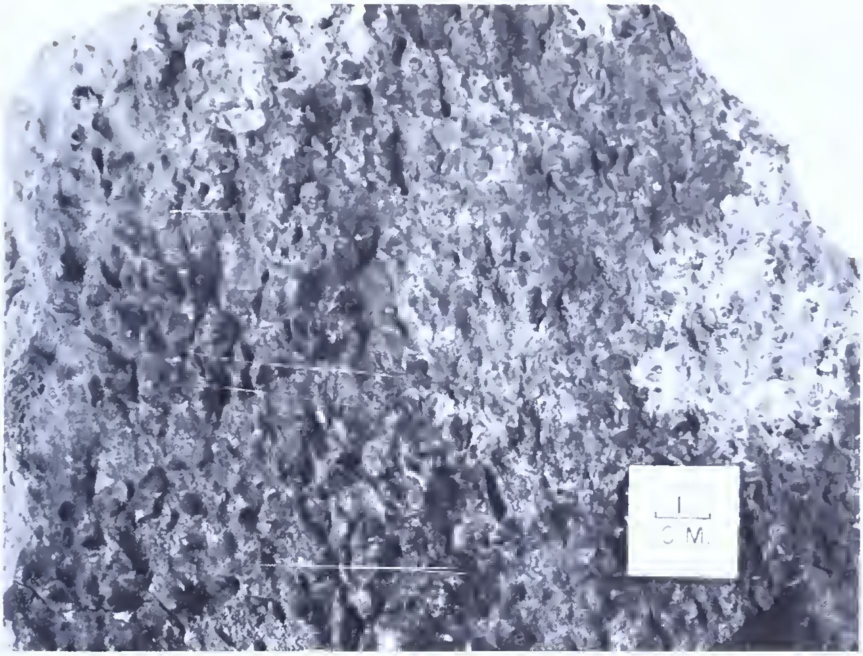


Figure 10. Coarse porphyroblasts of chloritoid in dark-green chlorite-epidate-albite schist from the Gargol muscovite phyllite pit.

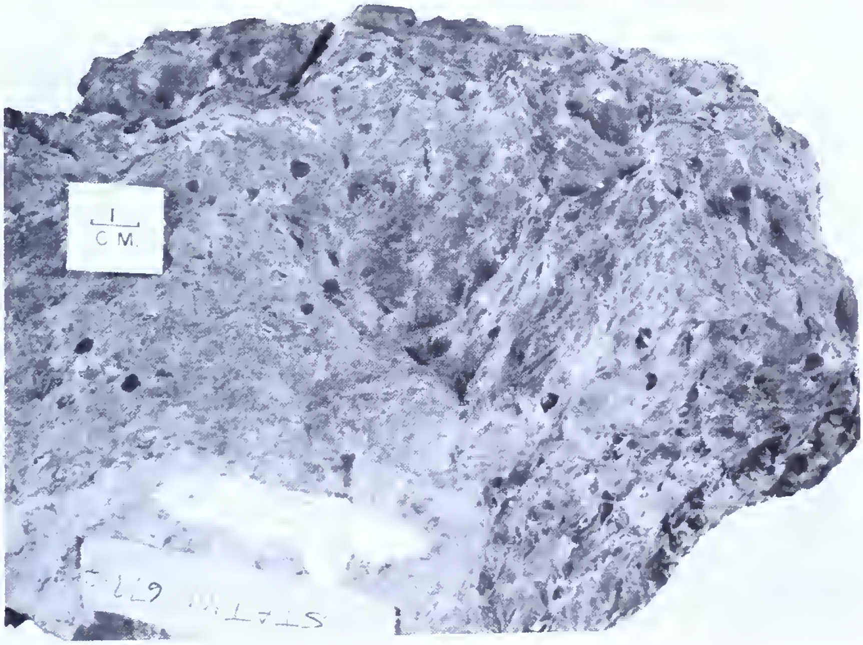


Figure 11. Coarse porphyroblasts of chloritoid in muscovite phyllite from the Gargol muscovite phyllite pit.

It cannot be shown whether the Loudoun Formation was entirely deposited after deposition of the volcanics or if some interfingering with the volcanics occurred. The following observations, bearing upon this relationship can be made:

(1). The Loudoun formed from pelitic sediments; this is inferred from local, well-developed layering in these rocks (Fig. 12) and their distinctive composition of muscovite and quartz.

(2). The Loudoun was deposited discontinuously as supported by its pod-like map pattern (Plate 1) and by the fact that the Weverton, the unit which normally overlies the Loudoun, rests directly upon the volcanics in some areas.

(3). The Loudoun rests upon, or at least in contact with, three different volcanic units—the aporhyolite, the aporhyolite porphyry and the lavender aporhyolite.

(4). The Loudoun is clearly overlain by the Weverton, but nowhere is it clear that it is overlain by the volcanics.

(5). Portions of the Loudoun are clearly younger than the volcanics as shown by the long narrow strip of muscovite phyllite which underlies the Weverton (Plate 1).

(6). The muscovite phyllite contains some volcanic material.

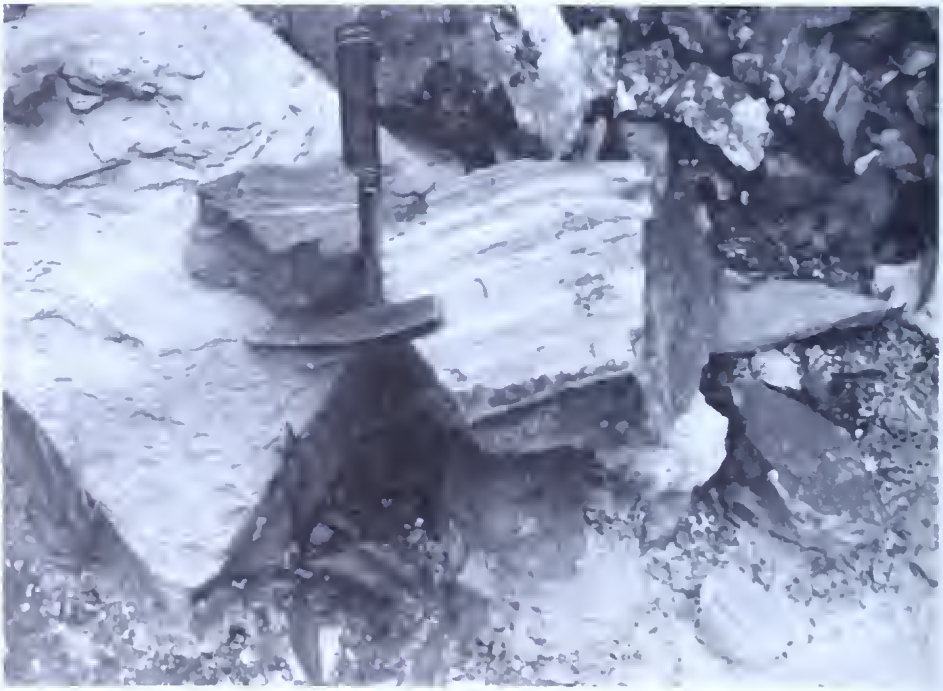


Figure 12. Layered metasedimentary rock from the Gargol pit.

The Loudoun could be shown to be unconformable upon the volcanics if a period of deformation prior to Loudoun deposition could be demonstrated. But no such period can be shown. Both overlying and underlying rocks have been involved in structural deformation on more than one occasion. Deformation patterns are similar in the different rock types, though they are more fully developed in the less competent muscovitic phyllite.

The Loudoun could have been deposited discontinuously if the surface of deposition was uneven. An uneven surface could result from erosion of uniform layers of volcanic flows, or from irregularly deposited flows. Either process could also account for the deposition of the Loudoun upon three different units.

In the absence of proof of deformation between the pelitic and volcanic rocks, it is thought most likely that the volcanics were laid down irregularly, creating local basins into which Loudoun sediments were deposited. Presumably the sediments were, at least in part, locally derived.

WEVERTON FORMATION

Weverton Quartzite was named by Keith for the type locality at Weverton, Maryland (1892, p. 365). Stose and Stose (1946, p. 37) recognized two quartzite members in Carroll and Frederick Counties, Maryland; Nickelsen (1956, p. 248) recognized three in the Blue Ridge near Harpers Ferry, West Virginia. In the Carlisle quadrangle G. W. Stose (1953) found the Weverton Formation to be "arkosic and conglomerate, but characterized by hard resistant ledges of conglomeratic quartzite." In the Mt. Holly Springs quadrangle, it has been possible locally to distinguish two members. Outcrops are prominent on ridges and on spurs and locally in stream valleys. At Hammonds Rocks, Rocky Ridge and The Peak, bold bluffs of Weverton quartzite rise 15-50 feet above the local topography and form prominent ridges.

Weverton Quartzite rests on lavender aporhyolite, muscovitic quartzite and muscovitic phyllite (Fig. 13). This probably results from the sporadic distribution of the last two rock types (Loudoun Formation).

Weverton Quartzite is generally light to dark gray but in some outcrops may have streaks or areas of lavender, pale green or white. It is a poorly sorted, fine-to coarse-grained, pebbly, schistose quartzite or quartzose schist with sericitic lenses or beds. Pebbles are dominantly vitreous vein quartz or fine-grained quartzite with lavender to purple and angular to subangular fragments of aporhyolite. Locally, magnetite octahedrons and angular to subangular kaolinized feldspar grains are scattered through the matrix. Local conglomerate or sand-size quartz

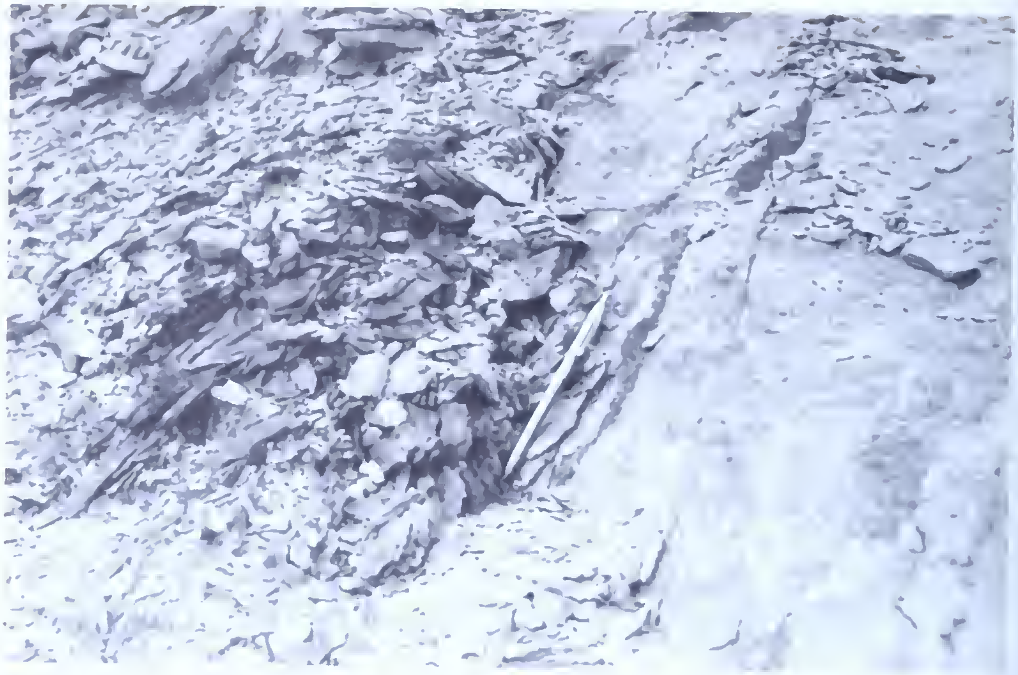


Figure 13. Contact between overturned Weverton quartzite and muscovite phyllite. Right half of photo shows bedding surface.

beds define bedding. Bedding ranges in thickness from one or more inches to a few feet. Schistosity is strongly developed and normally obliterates bedding. Locally, graded bedding is helpful in determining tops of beds. Structures which can be measured are bedding (S_0), flow cleavage or schistosity (S_1), shear or slip cleavage (S_2), joints, intersections of bedding and cleavage, crinkles, axial planes, and axes of rare minor folds.

It seems possible to distinguish two members of the Weverton Formation at Rocky Ridge. There the ridges formed by the limbs of a partly overturned syncline are conglomeratic. Along the axis of the syncline in lower ground northeast of Rocky Ridge, fine-grained muscovite-quartz schist is the dominant rock. This grades into finer and more siliceous rock toward the base of a foliated quartzite unit in the Montalto Member of the Harpers Formation. This fine-grained phase of the Weverton Formation has been mapped separately at Rocky Ridge. It cannot be mapped elsewhere, though the presence of a fine-grained upper member might explain the lack of outcrop along so much of the southeast slope of Piney Mountain.

In thin section, the conglomeratic member consists dominantly of rounded quartz grains many of which have been tectonically fractured throughout or granulated to angularity on grain edges. The quartz has strong undulatory extinction. Most grains contain dust inclusions and consist of more than one anhedral crystal. Surrounding the quartz grains is a mesh of granulated, very fine-grained (.015mm) quartz fragments and sericite flakes. The quartz fragments are squeezed into partially lenticular areas between grains with intergranular sericite following the lens shape or the dominant foliation. Locally sericite alone surrounds a quartz grain which is usually not granulated but rounded by rolling because the sericite absorbed the stresses.

The fine-grained member is composed of a matrix of very fine sericite flakes with numerous but not contiguous fine grains of lenticular quartz (average diameter 0.2 mm). In both members, scattered magnetite grains are present up to 5 percent and vary in degree of hematitic alteration. In purple aporhyolite fragments, fine-grained hematite is thickly disseminated. A few zircon and tourmaline grains also occur as accessory minerals. Because no sequence of exposures presents a complete section or makes possible a composite section, the thickness can only be measured from the map and cross sections. The conglomeratic member may be about 400 feet thick and the fine-grained member about 200 feet thick. The total thickness of the Weverton Formation is probably about 600 feet.

HARPERS FORMATION

The Harpers Formation was first described by Keith (1892, p. 265) and named the Harpers Shale (1893, p. 333) from a type section at Harpers Ferry, West Virginia. The Harpers Formation in that area is much more phyllitic (Nickelsen, 1956, p. 250) than in the Mount Holly Springs area where quartzite is dominant. Stose and Bascom (1929, p. 7) called attention to the increasing proportion of quartzite in the Harpers as follows: "The quartzite is only 20 feet thick at the southwest corner of the Fairfield quadrangle but thickens rapidly northwestward on the west side of Green Ridge and constitutes nearly all of the formation at the north end of the ridge." Stose (1906, p. 206) named the quartzite within the Harpers Formation the Montalto Quartzite Member.

In the Fairfield quadrangle, Stose and Bascom (1929, p. 7) calculate that the Harpers Formation reaches a maximum of 3,000 feet at Big Pine Flat Ridge and that the Montalto Quartzite Member constitutes about 2,250 feet of that thickness. The Montalto Member is in the center of the formation and is overlain and underlain by unnamed phyllite members.

In the Mount Holly Springs area and in quadrangles just to the west (John Fauth, personal communication) the existence of phyllite beds above and below the quartzite is in doubt. The Harpers Formation is represented, essentially, by the Montalto Member. Following standard practice, the Montalto Member might justifiably be raised to formation rank in this part of Pennsylvania. But because the area in which the phyllite members are absent is scarcely larger than a 15-minute quadrangle, the elevation in rank would serve no useful purpose and the member status is retained.

Montalto Quartzite Member

The Montalto Quartzite Member, representing nearly the entire Harpers Formation in the Mount Holly Springs area, underlies most of Keller Hill, Mount Holly, Trent's Hill and Piney Mountain, and all of French Hill. The best outcrops and section are exposed in the railroad cut of the Reading Railroad in Mount Holly Gap. The only other outcrops are on Keller Hill, French Hill, on the southeast slope of Mount Holly, northwest of Hunters Run, and one outcrop on Piney Mountain. This dearth of outcrops made investigation of the Montalto Member difficult and this was further complicated by the great similarity between the Antietam Quartzite and the *Skolithus*-bearing unit in the Montalto Member. Some control was provided by a set of winter aerial photographs taken in 1938, which exposed contacts marked by differential erosion. Chip-float traverses suggested by D. U. Wise (personal communication) provided additional control. On these traverses, a small float sample was collected every 100 or 200 feet, located (usually by altimeter and topographic features), described, and plotted with distance as the abscissa and elevation as the ordinate. The structure sections were drawn by correlating the above information with known structures and the data for the Montalto Quartzite Member (Plate 1).

During this intensive study it seemed possible to subdivide the Montalto Member. G. W. Stose (1929, p. 6) subdivided it as follows: "In the best exposures the Montalto Member is seen to comprise two divisions—the lower, a thick series of white vitreous quartzites: the upper, massive beds of softer white sandstone containing numerous straight slender scolithus tubes, 10 inches or more in length. Many of the beds of the lower division are streaked and cross bedded, with the fine black partings stained red by iron oxide. Others of these lower beds are light gray and veined with white quartz."

Table 2 presents the stratigraphy in the Montalto Member based upon observations in Mount Holly Gap, in the western part of Mount Holly, and on Piney Mountain.

Table 2 is a simplification of the stratigraphic succession, but mapping of each unit suggests that this breakdown has some validity. The "vitreous quartzite" matches the description of G. W. Stose's lower divisions of the Montalto Member (1929, p. 6), which could not be differentiated. The other three lithologic units do not match his descriptions. The "blue quartzite," a key horizon because it has a distinctive lithology, was used repeatedly to correlate stratigraphy.

Table 2.—*Units in the Montalto Member.*

Name (youngest to oldest)	*Description*	*Thickness* (feet)
1. "Greenish quartzite"	Thin-bedded, greenish-gray, brown-weathering, fine-grained quartzite with thin beds (1 to 6 inches) of phyllite or phyllitic quartzite	600
2. "Blue quartzite"	Fine- to coarse-grained (0.25-2.0 mm), dark-gray to bluish-gray arkosic quartzite with scattered grains of kaolinized feldspar	120
3. "Vitreous quartzite"	Fine-grained, white, vitreous, laminated to thick-bedded, feldspathic to arkosic quartzite with bedding, numerous *Skolithus*, and characterized by thin, black parting planes or bedding	300
4. "Foliated quartzite"	White, medium-to coarse-grained arkosic quartzite with well-developed slip cleavage	500
	Total	1520

Foliated Quartzite of the Montalto Member

"Foliated quartzite" underlies (Plate 1) (1) the "vitreous quartzite" and the "blue quartzite" in the anticline in Mount Holly Gap, (2) the core of Mount Holly Ridge, (3) an elliptical area on hill 1275 (Mount Holly), and (4) the crest of Piney Mountain and the slopes on its northeastward extension across Trent's Hill and across the lower slopes of Trench Hill. No outcrops were found. "Foliated quartzite" is distinguished by a well-defined slip cleavage (S_2), in which the grains are oriented parallel to the foliation. Individual grains show strong undulatory extinction and granulation. Intergranular areas consist of more finely granulated quartz, and a few muscovite flakes. In some thin sections, magnetite grains are abundant and grains of tourmaline, chlorite and biotite have been observed.

The "foliated quartzite" may be considered as either the basal unit of the Montalto Member of the Harpers Formation or an uppermost member of the Weverton Formation. The typical white color and dominance of quartz in the rock would make the former more plausible; the diagnostic cleavage, the latter. Arbitrarily it has been included in the Montalto Member.

Vitreous Quartzite of the Montalto Member

"Vitreous quartzite" underlies the following places (Plate I): (1) an arch between the "foliated quartzite" and "blue quartzite" in the anticline in Mount Holly Gap, and on both sides of the Mount Holly Gap, (2) the crest and sides of Mount Holly Ridge flanking the "foliated quartzite", (3) an elongate area around and southwest of the doubly plunging anticline on hill 1275, and (4) a belt northwest of the "foliated quartzite" on Piney Mountain and Trent's Hill, and on Trench Hill. Hand specimens are difficult to distinguish from Antietam quartzite which, however, usually lacks cross bedding and the fine parting planes.

Thin sections of "vitreous quartzite" were studied from the Eaton-Dykeman Paper Company's Upper Mill railroad cut, the Philadelphia Clay Company pit, and from southwest of the contact between the Weverton Quartzite and the Montalto Member at the west edge of the map on the southeast slope of Mount Holly. It is generally fine to medium grained (0.075-0.75mm) with strong undulatory quartz extinction. Grain contacts are sutured, with generally granulated to angular shapes. Some grains are completely shattered but many show slight grain elongation parallel to an incipient cleavage. Scattered among the quartz grains are a few plagioclase (An_{11-15}) grains with albite twinning and microcline grains, some of which are kaolinized. Flakes and interstitial areas of sericite occur among the quartz grains. A few grains of chlorite, biotite, magnetite, limonite, and calcite are also found. The texture is cataclastic.

Blue Quartzite of the Montalto Member

"Blue quartzite" is exposed in Mount Holly Gap and on hill 1133 of Keller Hill and above Upper Mill. On the basis of these outcrops and float, the following areas are believed to be underlain by "blue quartzite" (Plate I): (1) an anticlinal arch from Mount Holly Gap to the southeast side of Keller Hill, (2) possibly the valley southwest of the plunging nose of Keller Hill, (3) on Mount Holly in thin bands flanking "vitreous quartzite," (4) an elongate ring surrounding hill 1275, and (5) a long band on Piney Mountain.

In hand specimen, "blue quartzite" ranges from dark-gray to pale-bluish-gray and from arkosic to slightly feldspathic. Outcrop specimens from Keller Hill, Mount Holly Gap and the railroad cut at the Upper Mill of the Eaton-Dykeman Paper Company, and float from Piney Mountain were examined in thin section. Quartz shows strong undulatory extinction and granulation or shattering. The grains are angular to subrounded indicating deformation. Some grains are elongated, slightly oriented, pitted or clouded with fine dust particles.

Plagioclase, An_{12-24}, with albite twinning, and microcline are scattered among the quartz grains. Sericite, and in one specimen, chlorite, are intergranular with slight orientation. Magnetite, hematite, and limonite are intergranular, anhedral to euhedral at the edges of quartz or feldspar grains, or scattered as fine dust throughout the rock. Tourmaline and zircon are accessory. Grain sizes range from 0.0075 to 1.50 mm.

A thin, limonite-impregnated, sericite-quartz phyllite is interbedded with "blue quartzite" on top of Keller Hill and marks a gently dipping bedding plane near the crest of the anticline.

Greenish Quartzite of the Montalto Member

The "greenish quartzite" is exposed (1) on both sides of Mount Holly Gap, (2) in the railroad cut at the Upper Mill, and (3) along the northwest shore of the dammed pond southwest of the Upper Mill. It is presumed to underlie (1) the lower inner-slopes southwest of the plunging nose of Keller Hill which are covered by a thick Antietam Quartzite talus, (2) the lower slopes on the northwest side of Mount Holly, and (3) possibly on the lower northwest slope of Piney Mountain. It underlies lower topography than the other quartzites (Plate 1).

The "greenish quartzite" is the finest grained of the quartzites in the Montalto Quartzite Member. It is greenish gray but weathering develops brown to brownish-gray limonitic surfaces. Thin sections were studied from the railroad cut at Upper Mill, from the shore of the pond southwest of Upper Mill and from both sides of Mt. Holly Gap. The most striking feature is well-developed mortar structure. Individual quartz grains (0.15 to 0.26 mm) are angular to lenticular but completely surrounded by and oriented parallel to the foliation of abundant sericite and chlorite. Most of the chlorite and sericite are interleaved in an interconnecting matrix. Sericite also partly replaces feldspar (plagioclase, An_{16-20} and microcline). Biotite, zircon, magnetite and pyrite are accessory.

Harpers Phyllite

Stose and Bascom (1929, p. 6) found Harpers phyllite at both the base and the top of the Harpers Formation in the Fairfield quadrangle. No Harpers phyllite was observed at or near the base of the Harpers Formation in the Mount Holly Springs area. It may exist at that position but is not distinguishable from the top of the Weverton Formation.

At the top of the Harpers Formation on a hillside gully, 30 feet wide, near the north end of the Mount Holly Gap railroad cut, between Antietam quartzite and the "greenish quartzite" of the Montalto Member, there is a schistose quartzite which differs from most of the surrounding rocks. It could be a phyllitic, thin-bedded phase of the "greenish quartzite," but because it occurs at a critical point stratigraphically, is marked topographically by the gully, and is distinctive lithologically, it may represent the phyllite which is, to the southwest, the topmost unit of the Harpers Formation. It crops out only at the base of the gully at the level of the railroad. On the geologic map (Plate 1) it is mapped with the "greenish quartzite" unit of the Montalto Member.

Harpers phyllite may also underlie narrow topographic lows between "greenish quartzite" and Antietam quartzite at the northwest edges of Mt. Holly, and Piney Mountain, and at the northwest edge and under the high rim of Keller Hill.

Two distinctive rock types were collected. One is a phyllitic to schistose, limonite-stained quartzite with microgneissic structure. It is composed of alternate, very thin (1-5 mm) layers of limonite-impregnated sericite and chlorite with some elongate, oriented quartz grains and quartzite layers with a few sericite flakes surrounding more rounded and less well oriented quartz grains. The second specimen consists of striking alternations of thin, white quartzite layers (1-20 mm) and dark-gray, dense phyllite, both of which have been minutely folded (Fig. 14). Both contain plagioclase (about An_{15}) and microcline scattered among the quartz grains. Biotite flakes and zircon grains are accessory. Grain sizes range from 0.015 to 0.225 mm.

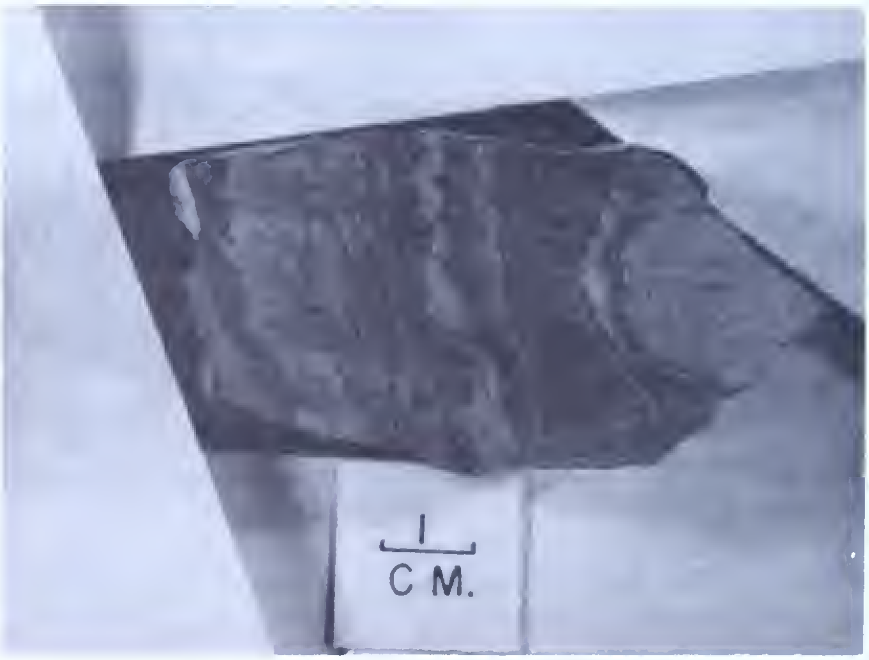


Figure 14. Hand specimen of Harpers phyllite showing folded quartzite layers (light color) and muscovite-quartz phyllite (dark color). S-surfaces include S_{II} parallel to S_1, and S_2, axial planes of minor folds. Collected from the Mt. Holly railroad cut.

ANTIETAM QUARTZITE

Keith (1892, p. 365; 1893, p. 335) recognized as a separate unit and named the Antietam quartzite. Stose and Bascom (1929), Stose and Stose (1944 and 1946) and G. W. Stose (1909, 1932 and 1953) traced the Antietam Quartzite to the Carlisle (15′) quadrangle of which the Mount Holly Springs (7½′) quadrangle is the southwest quarter. G. W. Stose (1953) indicated that Antietam Quartzite wrapped completely around Mount Holly and ran the full length of the west edge of Piney Mountain, Trent's Hill and Trench Hill. In the present investigation, the only indisputable Antietam Quartzite is restricted to the northwest slope of Mount Holly and Keller Hill and three patches along the nose of Keller Hill. It is questionable whether Trent's Hill and all of Trench Hill are Antietam Quartzite or "vitreous quartzite" beds of the Montalto Member. The two are difficult to distinguish lithologically and are separated on stratigraphic and structural evidence and by the presence of thin beds and cross bedding which are more common in the "vitreous quartzite." For this report, Trent's Hill and Trench Hill are considered to be underlain dominantly by "vitreous quartzite." This interpretation has been indicated in Plate 1.

Considering the depth of weathering (40-50 feet) observed in sand pits in Antietam Quartzite along the northwest slopes of Mount Holly, Keller Hill and Trench Hill, it is remarkable that any outcrops were found. Exposures were studied (1) at Bender's sand pit and nearby outcrops northwest of the Telegraph Relay Station on Mount Holly, (2) on both sides of the Mount Holly Gap, (3) in a sand pit 600 feet north of the north end of the Gap, (4) in outcrops and a sand pit on the inner perimeter of the plunging nose of Keller Hill, and (5) at one outcrop on peak 1118 on Piney Mountain. The only measurable section was exposed at the north end of the railroad cut in Mount Holly Gap. Using an average dip of 70°, the total thickness at this location, where Antietam Quartzite is exposed for 470 feet, would be about 440 feet. Because this location is on an overturned limb of an anticline, it is almost undoubtedly attenuated and represents a minimum thickness for the Antietam Quartzite.

At Mount Holly Gap and at the sand pit on the northwest limb of the plunging nose of Keller Hill the Antietam Quartzite may be subdivided into two members. The lower member is a fine-grained to silty quartzite with numerous scattered grains of kaolinized feldspar and local phyllitic quartzite layers. The uppper member is fine-grained to coarse-grained (at peake 1284 on Keller Hill), vitreous, colorless to light-brown, weathered quartzite with variable amounts of magnetite, rare feldspar grains and *Skolithus* tubes. Because the two members could not be mapped extensively, the subdivision is not shown on Plate I. Both members are thin- to thick-bedded, massive (except for local phyllitic layers), well-sorted (except on peak 1281 on Keller Hill), and have subrounded to subangular grains.

In thin section, a specimen from peak 1281 on Keller Hill is 99 percent quartz with some sutured contacts and a mosaic of more rounded grains. Strong undulatory extinction, local chlorite flakes, red to brown intergranular limonite grains and one zircon grain were observed.

Although the author found no fossils in the formation, G. W. Stose (1953) reported:

> Most of the quartzose sequence is unfossiliferous, except for *Scolithus* types that occur in the Montalto and Antietam. However, the upper layers of the Antietam generally contain molds and casts of trilobite spines, and shells of the brachiopod *Obolella*. In addition, Walcott (1896) reported the occurrence of *Olenellus* and *Hyolithus communis* in quartzite just above Mount Holly Springs, presumably in the Antietam. These fossils are of Lower Cambrian age.

AGE OF THE VOLCANIC AND CLASTIC ROCKS

Nickelsen (1956 (p. 253 reviewed the age of the Chilhowee Group (Table I) as follows:

> Age of the Chilhowee group must be considered in the light of recent discussions of the base of the Cambrian problem by Snyder (1917), Wheeler (1917), and King (1919). These writers advocate varying procedures in fixing the base of the Cambrian in areas where considerable thicknesses of strata conformably underlie the lowest fossiliferous zone. Wheeler (1947, p. 157) places the base of the Cambrian at the base of the *Olenellus* zone, Snyder (1917, p. 142) advocated putting the base of the Cambrian at the base of the lowest fossiliferous formation, and King (1949, p. 626-638), in the southern Appalachians, favors extending the Cambrian down through conformable strata to the unconformity or significant change in lithology beneath the lowest Cambrian fossil.
>
> In the southern and central Appalachians early Cambrian fossils have not been collected below the Antietam quartzite (or Erwin quartzite) at the top of the Chilhowee group. Resser and Howell (1938, p. 199) have advocated placing the base of the Cambrian below the Antietam and Erwin quartzites, but King (1950, p. 24) and Stose and Stose (1946, p. 29) favor placing it at the base of the Loudoun formation, 2000 or more feet below the Antietam, thus including all the Chilhowee group in the Cambrian. As was noted, Cloos (1951, p. 25-28) and Bloomer (1950, p. 781) suggest that the Cambrian may be extended still further to include the Catoctin formation. The writer considers the Chilhowee group Cambrian, because of conformity and lithologic similarity of its formation with the Antietam quartzite.

In the Mount Holly Springs area there is no new evidence on the age of the volcanics and lower clastic rocks. The volcanic rocks were extruded on land, and the clastics are apparently marine deposits. A possibility exists that some of the metabasalt may be spilitic and probably extruded into the sea. A time interval must have elapsed after the extrusions and before the seas invaded and covered the volcanic rocks. The presence of volcanic pebbles in the lower part of the Weverton Quartzite, the fine-grained lavender muscovite in the Loudoun Formation, and the presence of volcanic fragments in volcanic rocks and perhaps the purple color of aporhyolite all indicate an unknown period of erosion of the volcanics between flows and prior to deposition of the clastics. The volcanics can be either lowermost Cambrian or uppermost Precambrian on the basis of present knowledge. The latter age is used in this paper.

TOMSTOWN DOLOMITE

G. W. Stose (1906, p. 208; 1909, p. 5) named the Tomstown Dolomite in his work on the sedimentary rocks of South Mountain, Pennsylvania and the Mercersburg-Chambersburg area. Tomstown Dolomite underlies the foothills northeast and northwest of Mount Holly and Keller Hill and lies in the intermontane valley between those two uplands and Piney Mountain, Trent's Hill and Trench Hill. Outcrops are extremely scarce because this unit is relatively soluble and is easily eroded. A thick clay soil in lowland areas and rock rubble in the highlands covers it. Tomstown Dolomite was observed in only four localities; one of these was in the newly dug foundation of a residence, on the northwest slope of Mount Holly. This exposure was brown clay with relict folds of phyllite. The second occurrence is in the Carlisle (7½′) quadrangle to the north, at the intersection of the Boiling Spring Road with the Triassic diabase dike north of Red Tank. The dike is about 110 feet thick with a border of 12.5 feet of phyllitic and fine-grained recrystallized limestone. A section northeastward away from the dike is as follows:

Description	*Thickness in Feet*
1. Gray phyllitic dolomite with carbonate layers 4 inches thick	12.5
2. Deep-brown weathered clay (probably phyllitic limestone originally)	39.5
3. Brown pelitic limestone	10
4. Brown-weathering phyllite with local limestone beds..	few feet, then covered

The third Tomstown Dolomite exposure is in the pit of the Philadelphia Clay Company, northwest of Toland (Plate 3; Figs. 15, 16, 17 and 24). Here the Tomstown Dolomite is leached of almost all its carbonate, leaving a residual stratum composed mostly of variegated clays. A section was measured in the more westerly of the two generally north-south cuts as shown in Table 3.

A fourth location is an abandoned quarry in Tomstown Dolomite on the northwest side of Piney Mountain. No outcrops were found in this quarry.

No study was made of the clays in the section described above, nor of the white clay (G. W. Stose, 1907a) which is removed by open pit

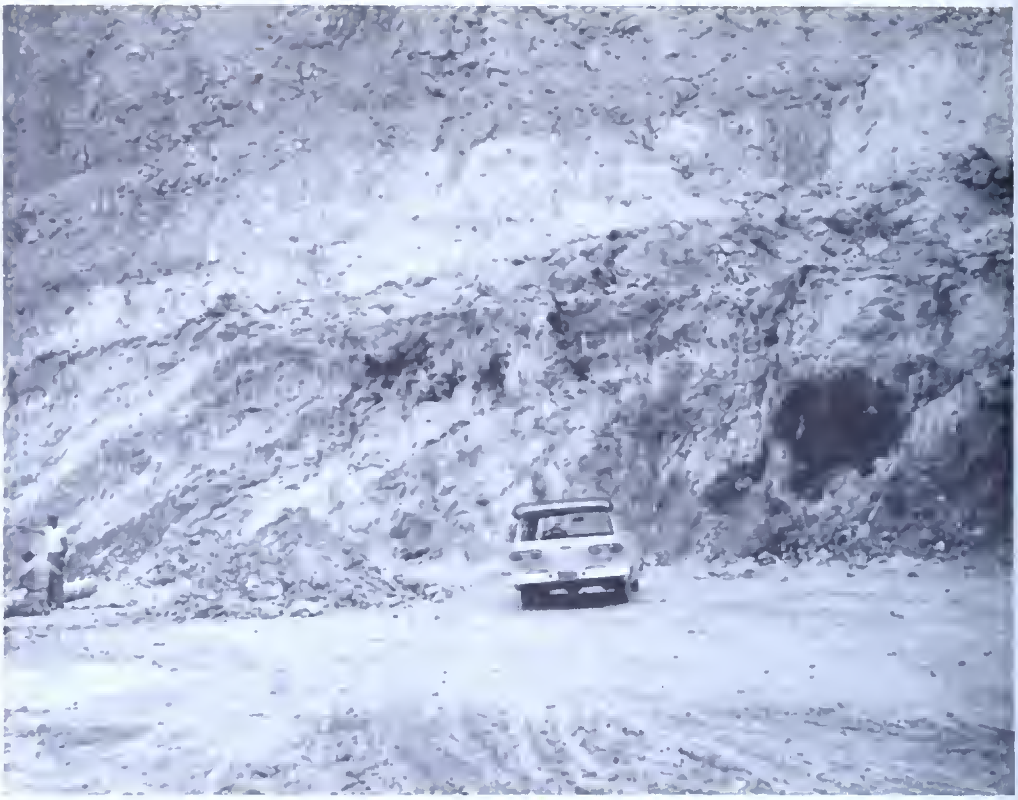


Figure 15. Working face at Philadelphia Clay Co. pit showing variegated clay with white clay at the upper level below Montalto "vitreous quartzite."

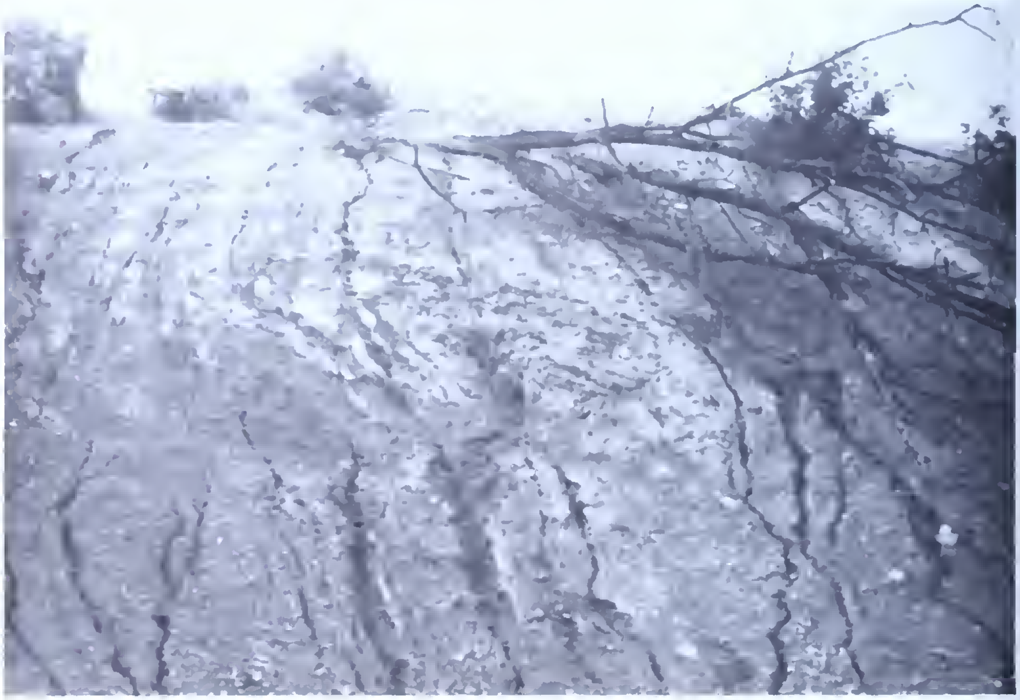


Figure 16. Philadelphia Clay Co. pit. Eroded clay wash over clayified Tomstown dolomite. Figure 5 on Plate 3 is a sketch of this face.

Table 3.—*Stratigraphic section along the western north-south cut in the Philadelphia Clay Company Pit.*

(Start traverse at intersection of north-south Valley Road and road to Philadelphia Clay Company office. First outcrop on south to north traverse is 146 feet north of the intersection.)

Distance (feet)	*Description*	*Thickness* (feet)
146-153	Variegated and yellow clay	7
153-161	Laminated yellow, brown, white, and gray clay, contorted	8
161-166.5	Variegated (red, blue, and gray) clay, horizontal	5.5
166.5-173.5	Laminated brown, yellow, and white clay, Bedding N23°W, 45°NW	7
173.5-175.5	Greenish-gray, brown, iron-stained clay	2
175.5-178.5	Brown and white clay, contorted	3
at 178.5	Fault, left-lateral, trends N33°W, vertical; stratigraphic separation is 5 feet based upon greenish-gray, iron-stained bed. Bedding on SW side is N83°W, 23°NW; on NE side is N43°E, 54°NW.	
	Traverse continued from NE side of fault.	
178.5-179	Greenish-gray, iron-stained clay	0.5
179-332	Covered	153
332-363	Laminated brown, white, and yellow clay, contorted	31
363-374	Alternating laminated to thin-bedded, brown, white, and gray clay. Folded N18°E, 55°NW to 60°SE	11
374-383	Alternating (1″ to 2″) thin-bedded, yellow-brown and greenish-gray clay. Well bedded—N32°E 72°NW Cleavage—N55°E, 50°NW	9
383-401	Alternating greenish-gray (to 5′) and laminated brown-yellow-white (to 5′)	18
at 401	Bedding—N54°W, 45°NW	
401-414	Greenish-gray and light-gray, edgewise conglomerate	13
414-420	Massive greenish-yellow clay. Bedding—N42°E, 74°NW	6
420-424	Greenish-gray and light-gray, edgewise conglomerate	4
424-452	Alternating layers of yellow-brown and phyllitic clay, contorted; horizontal to NW-dipping axial planes	28
452-466	Laminated, light-gray, massive shale; well-cleaved. Cleavage and bedding parallel—N30°E	14
466-474	Alternating thin layers of white and pink, light-brown and dark-brown clay	8
474-475.5	Finely laminated, massive, dark-gray clay (1 foot thick) with light blue-green clay layer to SE (6″) and olive-green clay layer to NW (3″). Bedding—N40°E, 77°SE	1.5
475.5-509.5	Thin-bedded clay, aternating greenish-gray and varying shades of brown.	34
	Local vertical fold at 500 feet.	
at 509.5	Bedding—N37°E, 58°SE; cleavage—N80°W, 62°NE	
509.5-564	Clay, alternating greenish-gray and brown layers	54.5
at 564	A broad anticline plunging NE developed on dark-green, iron-stained shale	

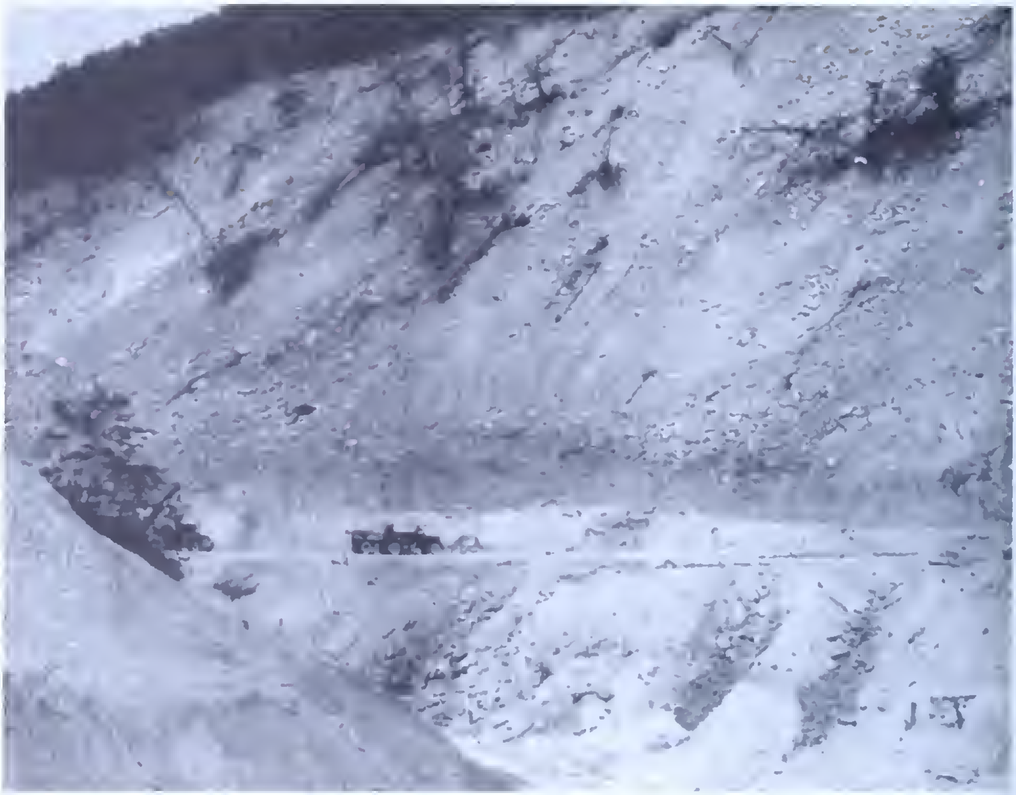


Figure 17. View west of Philadelphia Clay Co. pit showing clay bed below slide block of Montalto "vitreous quartzite."

methods by the Philadelphia Clay Company. A few interbeds in the deep north-south cuts have resisted the deep weathering of most of the Tomstown Dolomite. A thin-bedded, white to light-gray, slightly cherty dolomite, limonite-stained along bedding planes, consists of 80 percent dolomite and 20 percent quartz. The dolomite is very fine-grained with an average grain size of 0.015 mm. Quartz grains average 0.075 mm but reach a maximum of 0.30 mm. Both minerals are oriented parallel to bedding. Two other specimens of cherty dolomite examined in thin section are similar in mineral composition and grain size. One bed was composed dominantly of extremely fine-grained sericite (0.01 mm) with a few scattered quartz and dolomite grains. This rock lacked slaty cleavage but was laminated and is presumably a fine-grained phyllite.

The thickness of the Tomstown Dolomite is difficult to calculate. In the northeast roadcut leading into the pit, a height of 40 feet is exposed showing dominantly overturned folds for about 20 feet of section. The fold axial planes indicate overturned and recumbent folds, but in the pit the over-all attitude of bedding is vertical to dipping steeply northwest and the thickness would be about equivalent to the width of exposure except for thickening in crests and troughs of folds. Essentially

420 feet of section was measured in Table 3 which included some duplication by folding. G. W. Stose (1929) estimated 1,000 feet of Tomstown Dolomite in the Fairfield quadrangle. If the average width of the valley is halved to account for duplication by folding and thickening in crests and troughs, the thickness would be about 1,500 feet.

G. W. Stose (1953) states that the Tomstown Dolomite is rarely fossiliferous. Neither he nor this investigator found any fossils in the Tomstown Dolomite in the Mount Holly Springs quadrangle.

TRIASSIC ROCKS

The metavolcanic rocks are in contact along their southeastern boundary with Triassic sandstones. The difference in age of the two requires either a fault or an unconformable contact. The boundary line was drawn mostly on the basis of float and a few outcrops such as the exposure at Snyders Hill. No contacts were observed. No study was made of the sedimentary Triassic rocks which consist of gray to red, fine- to coarse-grained sandstones and conglomeratic sandstones.

All the rocks in the Mount Holly Springs quadrangle are cut by Triassic diabase or basaltic dikes. Borders of dikes and thin branching dikelets are aphanitic. Thicker dikes are phaneritic and diabasic. The dikes were mapped on the basis of easily identified float. The only outcrops of diabase in the Mount Holly Springs quadrangle occur at Red Tank, north of the plunging nose of the anticline at Keller Hill. Two dikes apparently pinch out south of Goodyear and north of Myerstown, respectively. A third cuts across Trench Hill forming a gap, transects the plunging nose of Keller Hill, and transverses the quadrangle with a sinuous path. The best exposure is north of the map on the Boiling Spring Road, where the dike is 110 feet thick and has recrystallized the Tomstown Dolomite for a distance of 12.5 feet. There is little evidence of its thickness elsewhere.

In thin section, the diabase is composed of clinopyroxenes, labradorite, quartz, magnetite and pyrite. The clinopyroxenes are partly uralitized to green or brown fibrous actinolite. Plagioclase, An_{55}, is subophitic with clinopyroxene and the centers of plagioclase grains are altered to mica. Quartz occurs as interstitial clear anhedral grains composing about 5 percent of the rock.

METAMORPHISM

The rocks of the Mount Holly Springs quadrangle belong to the green-schist facies (Turner and Verhoogen, 1951, p. 165-173). Metamorphism in the area was accomplished, for the most part, by dynamic or regional deformation with minor local contact metamorphism resulting from the intrusion of Triassic dikes. The mineral assemblage in the volcanic flows includes chlorite, epidote, actinolite, albite and quartz, which are typical of the green-schist facies. The phyllite of the Harpers Formation was originally a silty shale. The silt bands have been metamorphosed to quartzite and the pelitic layers to sericite and chlorite. Plagioclase in metabasalt, An_{15}, indicates that albitization of the originally more calcic plagioclase is not in equilibrium. The presence of a few relict, detrital biotite flakes would also indicate the same. This mineral assemblage would assign the Harpers phyllite to the muscovite-chlorite subfacies of the green-schist facies. Microcline has essentially not been affected by metamorphism. The quartzites in the Montalto Member of the Harpers Formation and the Antietam Quartzite mostly show cataclastic effects such as granulation and shattering of quartz grains. The intrusion of the Triassic diabase into the Tomstown Dolomite recrystallized the phyllitic dolomite for a distance of 12.5 feet from the contact. This made the limestone more brittle and the phyllite slaty. The most striking effects of deformation are the formation of well-developed cleavage, porphyroblasts and relict phenocrysts elongated in tectonic "a."

STRUCTURAL GEOLOGY

TERMINOLOGY

Terminology used for structures is that recommended by Freedman and others (1946, p. 624) as follows: "*S* is any surface or plane of inhomogeneity. *L* stands for any linear feature in the rock. *F* represents a fold defined by any deformed S-surface. *A* is a fold axis defined by any deformed *S*-surface. *D* is a period or time of deformation."

S_0 represents bedding; S_1, S_2, etc. are surfaces which cut or deform S_0 or another pre-existing surface. In extrusive rocks, S_0 may be used to designate flow layering. Intersections of surfaces produce lineations, e.g. $L_{1\times2}$. A fold created in D_2 time which is defined by S_0 would be designated $F_{0\times2}$. Inasmuch as most folds involve bedding the zero is dropped for axes of folds involving bedding and are designated A_1, A_3 for the time D_1, D_3 during which they were folded.

S_1 is almost invariably a flow folding that produced planes of cleavage generally parallel to F_1 axial planes and locally parallel to bedding in metasedimentary rocks and to layering in metavolcanic rocks. In most rocks S_2 is a shear or slip cleavage that offsets the S_1 and is parallel to F_2

axial planes. In the highly micaceous muscovitic phyllite, S_2 is another flow cleavage, similar in appearance to S_1 in other rocks but offsetting the previously formed S_1. Axial planes of numerous F_2 folds in the easily deformed muscovite phyllite may not have been formed at the same time as S_2 cleavage planes in the quartzites. A structure in a resistant rock type may not have been formed at the same time as a structure with the same number in an easily deformed lithology. S_3 occurs as limited fracture cleavage in brittle rocks and as kink bands in easily deformed rocks. Smear lineations are indicated by their tectonic movement, "a" or "b."

Structural data were compiled on equal area nets using the lower hemisphere.

STRUCTURES

The South Mountain anticlinorium is a culmination and a salient along the axis of greatest curvature in the Appalachian belt. The oldest rocks in the Blue Ridge province of Pennsylvania have been raised to the surface and pushed northwest in a series of doubly plunging folds (Fig. 2 and Pl. 1). The named folds in the Mt. Holly Springs area from northwest to southeast are Benders quarry anticline, Mount Holly anticline, Hammonds Rocks anticline, Mountain Creek Syncline, Goodyear anticline, Rocky Ridge syncline, Whiskey Spring anticline, The Peak syncline, Stone Head anticline, Fickels Hill syncline, and Snyders Hill anticline. There is, in addition, a sequence of an unnamed syncline, an anticline, and a syncline.

The area has been faulted by a thrust, and by three major high angle faults, with minor break thrusts along them, parallel to the regional northeast trend. Five lesser, and presumably later, transverse faults offset the continuity of the ridges and valleys. The Triassic sedimentary rocks have been downdropped relative to the South Mountain anticlinorium as a consequence of Triassic step faulting along this contact.

Cleavages (S_1, S_2, and locally S_3) deform primary structures and provide key data on the overall structure of the region. Joints cut all rocks and yield information about later forces which affected the rock formations.

Structural data compiled are:

1. Geologic contacts and faults shown on the geologic map (Plate 1) and cross sections (Plate 1a)
2. Bedding, cleavages, and lineations shown on the geologic map (Plate 1b)
3. Bedding, cleavages, and lineations for specific areas shown on equal area nets (Plate 2)
4. Joints shown on separate equal area nets (Figure 23).

On the geologic map, Plate 1, observed boundaries are rare, e.g. between muscovite phyllite and Weverton Quartzite at the Goodyear muscovite pit and between Antietam Quartzite and Harpers phyllite in Mount Holly Gap. A solid line boundary was used wherever some lithologic control was observed in the field or coincided with a lineament on an aerial photograph, a dashed line where there is some evidence for the boundary, and a dotted line where the boundary was drawn to satisfy geologic requirements.

The rocks in the Mount Holly Springs (7½′) quadrangle have been folded by one or more deformations. Stose (1953) states as follows: "Relations in the Carlisle quadrangle indicate that the series was closely folded and deeply eroded before Lower Cambrian times. Alternating belts of rhyolite and slate that strike northeast are truncated by Lower Cambrian beds in the vicinity of Rocky Ridge, Long Mountain and Stone Head." At another point, Stose states as follows: "An earlier period of faulting in Late Ordovician time probably also affected this part of southeastern Pennsylvania." These quotes indicate that Stose believed as follows:

1. That there was a deformation between the extrusion of the flows and the deposition of the Lower Cambrian clastics;

2. That although most of the deformation took place during the Appalachian revolution, overthrusting did occur during the Ordovician. This would imply at least three deformations: one in the Precambrian, one in the Ordovician, and one during the Appalachian revolution. Cloos (1950) concludes that all deformation took place during several stages of one deformation.

There is no conclusive evidence for a deformation between the Precambrian (?) volcanics and the overlying clastics. Some erosion of the volcanic rocks did occur as evidenced by fragments found in the overlying clastics. However, all the rocks in the area were subjected to more than one deformation (Plate 2), based on the presence of S_1, S_2, and S_3 in all rock types. Each S-surface after S_0 offsets or folds the lower numbered S-surface or surfaces that preceded it. They were presumably developed in D_1, D_2 and D_3 time. D_1 must be younger than the Tomstown Dolomite. Most probably D_1 corresponds to one of the dates established in the Pennsylvania Piedmont (Lapham and Bassett, 1964) such as a possible Taconic orogeny 460 million years (m.y.) ago. S_2 may have formed in a second well-recorded orogeny (D_2), about 330-350 m.y. ago in early Carboniferous time. The D_3 pattern could then have formed in the late stages of the Appalachian orogeny, after early Carboniferous time. Alternatively more than one deformation pattern may have developed during stages in a single orogeny.

The following planar and linear features were observed in the Mount Holly Springs quadrangle:

1. Bedding in the clastics,
2. Layering in the volcanics,
3. Cleavages, joint faults and lineations in tectonic "a" (transverse to the fold axis) and "b" (parallel to the fold axis). In metabasalt, the only layering is an alignment of amygdules and local layers of black manganese oxide which have stained and impregnated phyllite (probably a soil or tuffaceous layer) where these are interbedded between flows. The lineations were almost invariably parallel to cleavage either by coincidence or as a result of being drawn into the plane of cleavage by deformation. Most of the numerous outcrops on the west slope of Fickels Hill (Fig. 5) are composed in part of these layers.

In the aporhyolites primary features were obliterated by later flowage. Almost every example showed banding (bedding) essentially parallel to the direction of cleavage. This could mean that

1. the volcanic flows have been tilted to the southeast as one limb of a major fold; or
2. all primary features have been distorted by deformation into the plane of flow cleavage; or
3. folds are overturned to the northwest so that all limbs dip southeast.

In the fine-grained muscovite quartzite and muscovite phyllite of the Loudoun Formation there are a few examples of compositional banding which may give the attitude of bedding. In addition, these fine-grained rocks show one or more cleavages and lineations.

In outcrops of the Weverton Formation, bedding is defined by conglomeratic or sandy layers. The cleavage masks these and makes them difficult to find. At one of the rare contacts between formations, the muscovitic phyllite of the Loudoun Formation is in direct contact with the Weverton Formation in the western pit of the Goodyear muscovite pits. Here the contact dips 35° to the southeast with the Loudoun muscovite phyllite lying above the Weverton Formation. This is an inverted relationship. Dip of bedding in the Weverton Formation near the west edge of the map changes southeast to northwest. The change in dip and strike must result from a gradual steepening of the overturned bed until it is right-side-up, as indicated by dips to the northwest of 73° and 42°.

In the Montalto and Antietam quartzites compositional banding of phyllitic layers in the massive quartzite probably marks bedding. In the "vitreous quartzite" of the Montalto Member which shows no compositional banding, possible bedding can only be determined by observing a surface perpendicular, or nearly perpendicular, to *Skolithus* tubes. In Harpers phyllite white silty quartzitic bands in the dark-gray phyllitic layers mark compositional banding strikingly.

Bedding was observed on Keller Hill, French Hill, Rocky Ridge and The Peak. S-surfaces other than bedding, S_1, S_2, and S_3, are best explained in terms of specific localities. Equal area nets (Plate 2) illustrate the position of each of the S-surfaces and lineations in the area.

S-SURFACES AND LINEATIONS

In Plate 2, Fig. 1, structural data are shown for the Mount Holly railroad cut, the Eaton-Dykeman Paper Company railroad cut at Upper Mill, and the northwest shore of the pond at the foot of Mount Holly which exposed subdivisions of the Montalto Member of the Harpers Formation, phyllite of the Harpers Formation and Antietam Quartzite. A strong concentration of poles to bedding and cleavage form a partial girdle striking about N60°E and dipping variably southeast. These indicate that the north-west limb of the Mount Holly anticline is overturned to the northwest whereas the southeast limb dips gently southeast. S_1 strikes northeast and dips moderately southeast only on the overturned northwest limb. Intermediate in dip is an F_2 axial plane observed both at Upper Mill railroad cut and on the west bank of the pond. Cleavages indicated as S_2 are fracture cleavages in brittle quartzite on the northwest limb of the Mount Holly anticline with steep to moderate northeast dips and striking N50° to 70°NW from northeast to northwest. Steeply plunging *Skolithus* lineations are present in the gently dipping southeast limb, and gently plunging *Skolithus* lineations are present in the steeply dipping, overturned northwest limb. *Skolithus* is distorted from perfect perpendicularity to bedding and locally has developed a sigmoid shape from drag between incompetent beds. A smear lineation of aligned minerals plunging southeast at gentle to intermediate angles forms an "a" lineation only on the overturned north limb.

In Plate 2, Fig. 2 are structural data for Benders quarry in Antietam Quartzite on the northwest flank of Mount Holly. Poles to bedding (S_0), define a partial girdle for a southeast- and a northwest-dipping limb of an anticline. The axial plane of a gently plunging anticline bisects the spur on which numerous levels were quarried for sand. At lower levels on the northwest limb, the dip steepens to 79° but is nowhere overturned. In a small quarry southeast of the main quarry and south of the peak of the hill, northwest dips define a syncline asymmetric to the northwest (Plate 1). *Skolithus* lineations plunge southeast and range from gently plunging on the steeper limbs to almost vertical on the more gently dipping parts of limbs. S_1 fracture cleavage, dipping steeply to moderately northward, suggests that it fans the fold.

In Plate 2, Fig. 3 data are compiled on the "vitreous quartzite" unit of the Montalto Member and Tomstown Dolomite at the Philadelphia Clay Company pit on the southeast flank of Mount Holly. The "vitreous quartzite" (Montalto) forms a partial girdle trending generally east-west and dipping gently to moderately. These attitudes and field observations on the scarred slope above the quarry suggest that an enormous block of "vitreous quartzite" (Montalto) slid down the side of Mount Holly, overrode the younger Tomstown Dolomite, and formed a series of anticlines and synclines with a generally north-south axial plane (Fig. 17).

Bedding (S_0) and F_1 and F_2 axial planes of Tomstown Dolomite form a broad complete girdle about N30°W to S30°E (Pl. 2, Figs. 2, 3, 4, and 5). The 40° spread in strike in the Tomstown Dolomite probably reflects deformation resulting from down-faulting or landsliding. Most of the F_1 axial planes in the Tomstown Dolomite strike about N60°E. The folds are asymmetric to recumbent (Figs. 18 and 19) with wave lengths ranging from inches to hundreds of feet. Locally, S_2 with moderate to steep dips transects the folds. A_1 and scarce L_{0x2} plunge moderately to gently northeast and southwest.

In Plate 2, Fig. 4, the equal area net of the Goodyear muscovite phyllite presents structural data of the Loudoun muscovite phyllite and Weverton Quartzite. Bedding was observed only in Weverton Quartzite and at its contact with the underlying overturned muscovite phyllite. It strikes N25°-50°E and dips 30°-45°SE. S_1 is generally parallel to bedding but has a wider range in attitude in both rock types. S_2 dips more steeply 50°-60°SE than S_0 and S_1. In general S_3 (kink planes) dip steeply but have no uniformity in strike. Intersections of four surfaces (S_0 through S_3) can yield six lineations. Five of these intersection lineations were observed. L_{1x2} plunges gently northeast and southwest and ranges in strike from N20°-60°E. L_{2x3} plunges down the dip of S_0, S_1, and S_2. L_{0x1} has a similar orientation to L_{1x2}. L_{0x2}, showing no concentration, plunges gently southeast as an "a" lineation. As S_3 has variable strike, L_{1x3} scatters around the circumference with moderate to gentle plunge. It has a right lateral sense of shear. A smear lineation of oriented muscovite flakes in tectonic "a" plunges moderately southeast.

In Plate 2, Fig. 5, there is a compilation of data for the Gargol muscovite phyllite pit in the Loudoun Formation with its varied lithologies including black phyllite, brown-weathering andesite, chloritoid-muscovite schist, chloritoid-chlorite-epidote schist, chlorite-epidote schist, and schistose gray rhyolite. S_0, marked by the contacts between the different lithologies, strikes N35°-40°E, and dips 30° to 60° SE. S_1, flow cleavage, has a wider range but generally parallels S_0, striking N20°-75°E, and dipping 20°-65°SE. S_2 is also a flow cleavage and forms the axial planes of numerous tight isoclinal flow folds, F_2. S_2 is steeper than S_1 and varies

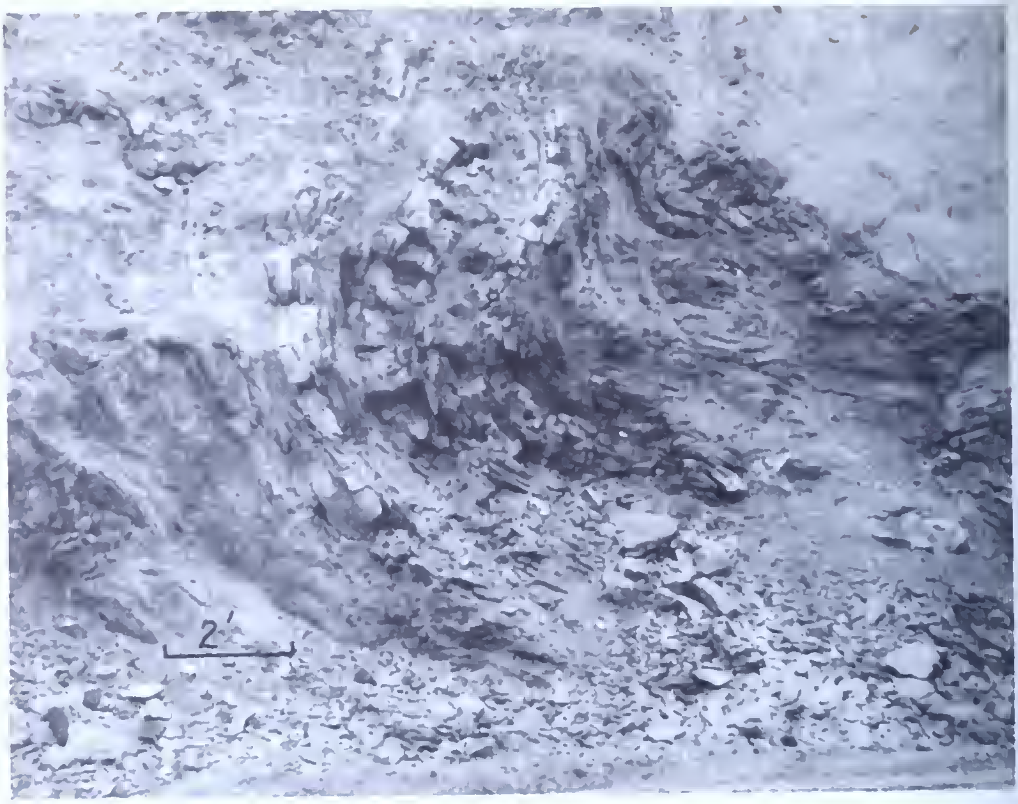


Figure 18. Entrance cut at northeast end of clay pit showing anticline (?) folded past recumbency in chert and shale of the Tomstown Formation.

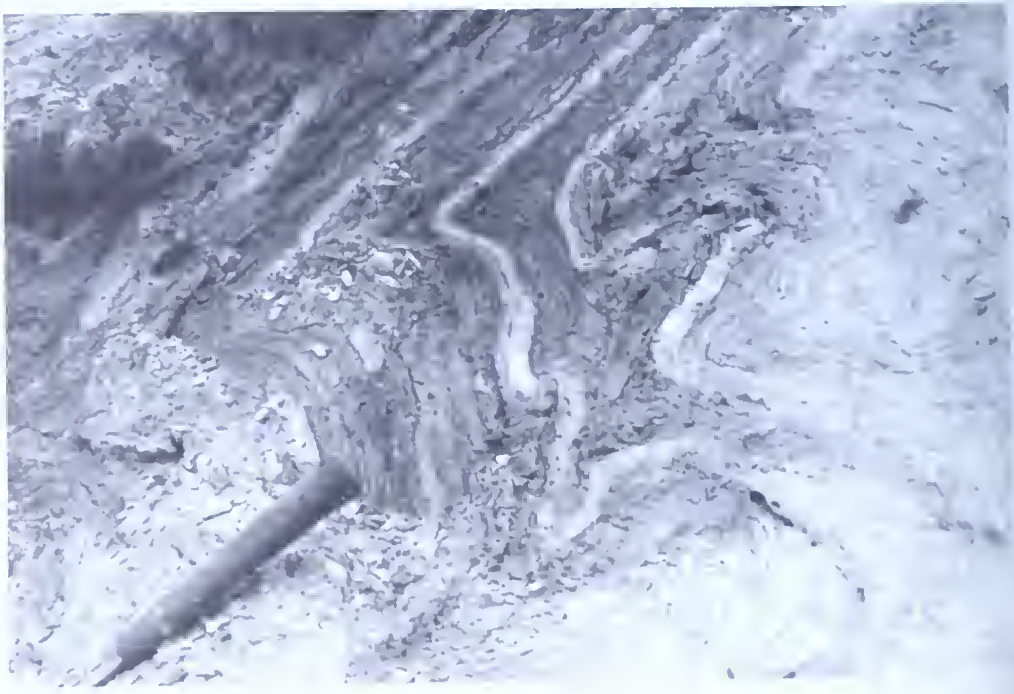


Figure 19. Recumbent folds in clay altered from Tomstown dolomite on the east wall of the Philadelphia Clay Co. pit.

in strike from N20°W to N20°E. Typically, L_{2x3} varies considerably in strike and dips steeply. A_2 plunges uniformly northeast at moderate to gentle angles. L_{1x2} forms a cluster that plunges moderately southeast, and L_{2x3} ranges widely to show a pattern consistent with the suggested peripheral girdle of S_3.

In Plate 2, Fig. 6, are data for metabasalt from Fickels Hill and an area southwest of it. The dominant structure is a flow cleavage (S_1) which apparently varies widely in strike. It is probably more uniform than the plot shows. Some outcrops are rich in magnetite which probably attracted the compass needle even at a distance, and there was some question about whether all readings were on outcrop. The general clustering of S_1 indicates a northeast strike and moderate dips. S_2 is a slip cleavage that was observed locally with a dip generally gentler than the associated S_1. S_0 was plotted only where amygdules indicated possible upper surfaces of flows and where black phyllite was in contact with massive metabasalt. The amygdules locally gave the impression of being oriented in S_1, which may account for their similarity in attitude. L_{1x2} and L_{2x3} plunge gently southeast but there are too few such lineations to deduce reliable conclusions. The smear lineation of chlorite flakes and epidote grains is uniformly in tectonic "a." S_3 is scarce and occurs as a fracture cleavage particularly in massive epidosite. It strikes about N15°W and dips steeply northeastward similar to some S_3 in Figures 4 and 5 on Plate 2. The character of S_3 in the metabasalt and in the pelitic rocks is controlled by the competence of the rocks.

In Plate 2, Fig. 7, data are presented for aporhyolite porphyry from the outcrop on State Route 94 south of Trench Hill. S_0 represents the attitude of changes in lithology from schistose aporhyolite porphyry to thin layers of muscovitic phyllite. Due mostly to folding, the attitude of S_0 varies from N40°W to N45°E. S_1 is a flow cleavage with a range similar to S_0 possibly because of rotation of bedding into the plane. S_3, a slip cleavage, forms a small cluster about N80°W, 70°SW similar to some S_3 in the other areas. Two fold axial planes have a similar orientation to S_3. L_{0x1} and L_{1x3} and "a" lineation plunge moderately northeast and southeast respectively.

Summary

S_1 has developed uniformly over the area and represents the most consistent regional deformation. These are the attitudes illustrated in the cross sections (Plate 1). S_1 has apparently dragged S_0 into its attitude. Where S_2 is developed, it varies only a little in strike except in the brittle quartzites of the Antietam and Montalto quartzites in the Mount Holly railroad cut. S_3 has formed kink planes in the easily deformed muscovite phyllites but a slip cleavage in the aporhyolite porphyry. The major

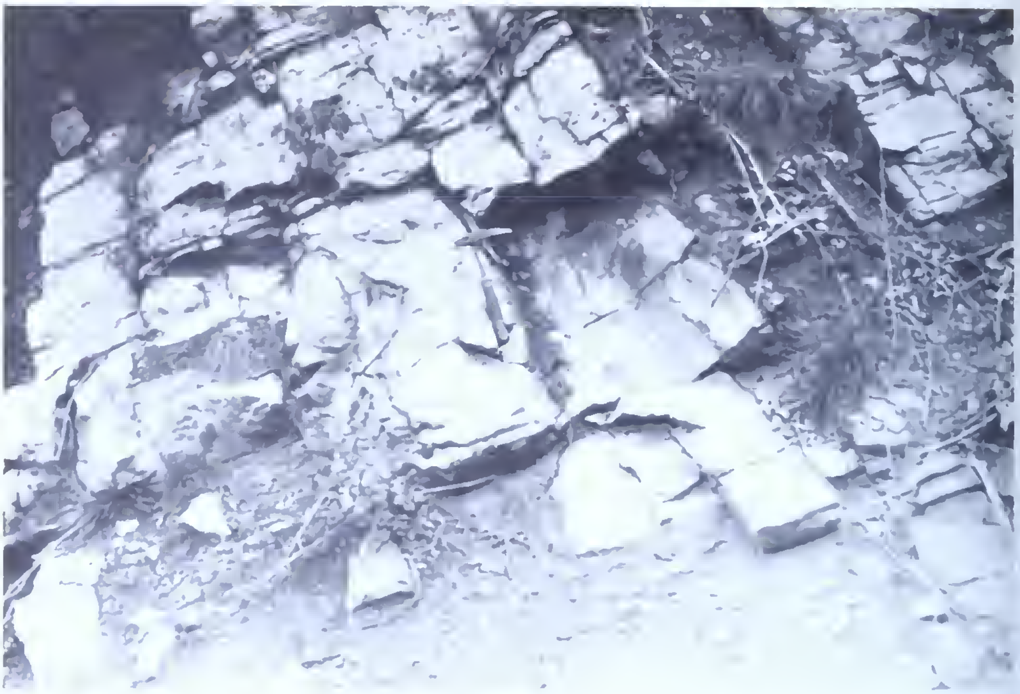


Figure 20. "Vitreous quartzite" of the Montalto Member showing traces of overturned bedding (dipping to right) and joints (visible surfaces) exposed in north end of railroad cut through gap at Mt. Holly Springs.

contributions of these diagrams is that they indicate multiple deformation and that there has been little or no change in the stress distribution with each deformation as indicated by the common attitude of S_0, S_1 and S_2.

FOLDS

Most of the 11 folds identified in the Mount Holly Springs (7½′) quadrangle are doubly-plunging either within the map boundaries or on extensions of the folds (see Pl. I). Thinning on limbs and thickening of crests and troughs indicate similar folding. Where the Blue Ridge prong in Pennsylvania is at its widest and exhibits the greatest curvature, the number of folds is a maximum. The axes of the folds converge and join toward the northeast as the Blue Ridge narrows and terminates and to the southwest toward the axis of the first recess away from the salient. The major folds are discussed from northwest to southeast. In the following discussion, the term "second-order folds" is used for small folds which are subsidiary digitations on larger folds and which do not contain a major anticlinal or synclinal axis.

The northernmost first-order fold in the Mount Holly Springs quadrangle is the Mount Holly anticline. Stose (1953), called it the Hammonds Rocks-Mount Holly anticline. The axis shown on Plate 1 differs from that of Stose (1953) because subdivision of the Montalto Member brought out second-order folds which shift the axis from the position which he indicated. The axis curves and is probably offset by a number of transverse faults. Mount Holly anticline is partially overturned to the northwest and plunges about 15°NE. Antietam Quartzite rims the northwest flank and the nose, and all older formations and members were involved in the folding down to the Weverton Quartzite core at the west edge of the map, and the older volcanic rocks west of the map.

The Hammonds Rocks anticline converges toward the Mount Holly anticline separated by an unnamed syncline. The latter is delineated by dips in outcrops of Weverton Quartzite near the west edge of the map (Plate 1). Outcrops of Weverton Quartzite at Hammonds Rocks and on the hill east of it define the axis of the anticline (Figure 21). Aerial photographs, which also show the fold, indicate that the syncline closes southwest of the map boundary, plunging northeast.

The next first-order fold southeast is the Mountain Creek syncline (Stose, 1953, and Plate 1) modified by downfaulting. Its northeastward divergence indicates that it also plunges northeast. It has been downdropped between Mount Holly and Piney Mountain. Piney Mountain and Trent Hill represent the overturned northwest limb of the next anticline to the southwest. Beds of Montalto Quartzite dipping steeply southeast are evidence for overturning found southwest of the map. The northwest dips on Trench Hill probably delineate the southeast limb of the Mountain Creek syncline and the northwest limb of the anticline at the northeast end of Trench Hill. Drag on the Mountain Creek graben could also help account for the northwest dips. The northeast end of Trench Hill wraps around and plunges northeast under the Tomstown Dolomite. The angle of plunge was not determinable.

The Goodyear anticline has a curving axis that plunges into a structural depression east of Hunters Run. The principal evidence for the location of this axis is stratigraphic, based on the interpretation in the cross sections (Plate 1a).

The area underlain by Weverton Quartzite, Loudoun Formation, and volcanic rocks is overturned with all limbs southeast of the crest of Piney Mountain dipping southeast. The evidence is based largely on steep dips presumably overturned in the Weverton Quartzite on the southeast slope of Piney Mountain near the west end of the map. The beds are overturned to the northwest and dip gently southeast near their contact with the muscovite phyllite; the dip steepens northwestward until it becomes right side up on the northwest slope of Piney Mountain.

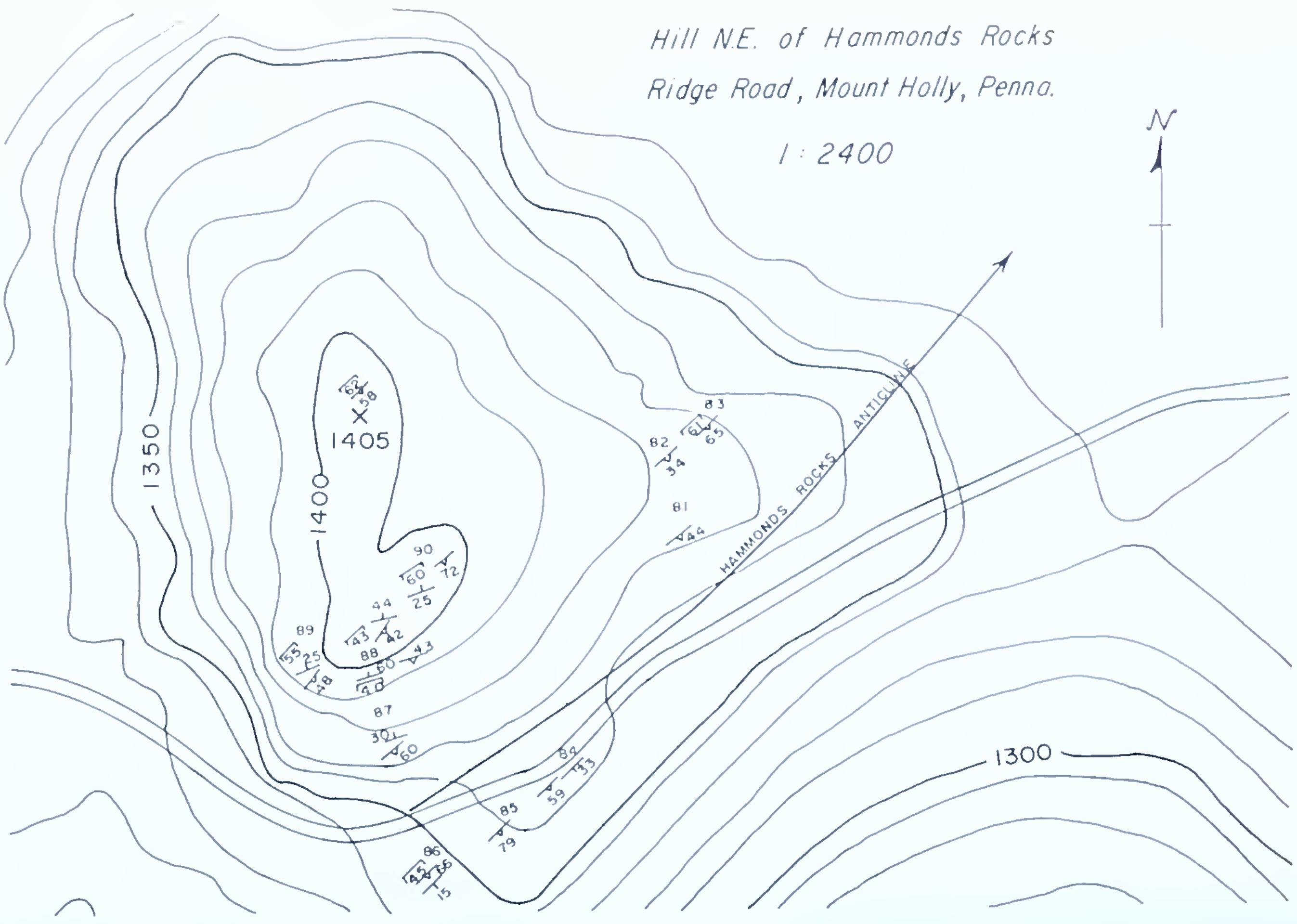


Figure 21. Detailed structural measurements showing course of the Hammonds Rocks anticline on the hill northeast of Hammonds Rocks along Ridge Road on Mt. Holly.

The Rocky Ridge synclinal axis was located by the attitude of beds in the Weverton Quartzite on the limbs of the syncline. The extension of its axis and the axes of the Whiskey Spring anticline, The Peak syncline, the Stone Head anticline, Fickels Hill syncline, Snyders Hill anticline and the three folds to the southeast, are based largely on stratigraphic evidence on the map (Plate 1) and the cross sections (Plate 1a).

Rocky Ridge outlines an overturned syncline plunging northeast. The limbs of the syncline are underlain by conglomeratic Weverton Quartzite, and the basin between them by finer grained Weverton Quartzite. Stose (1953) considered the area surrounding the ridges to be underlain by the Loudoun Formation. The Loudoun Formation, redefined here to consist of muscovitic quartzite and muscovitic phyllite, underlies the outer area only. The southeast limb of Rocky Ridge should dip northwest as the southeast limb of a northeast-plunging syncline but it is overturned to the southeast.

The Peak, underlain by conglomeratic Weverton Quartzite, is apparently one limb of a fold dipping southeast. However, a roadside outcrop of Weverton Quartzite, east of The Peak, dips 68°NW, and the presence of the "vitreous quartzite" of Montalto Member at the top of Long Mountain indicate that The Peak and Long Mountain are synclinal. The Peak is probably the attenuated closure of the two limbs.

There are numerous second-order folds (Plate 1) some of which are described below. At the nose of Keller Hill, the Antietam Quartzite and possibly two of the Montalto Member quartzite units are folded into a symmetrical syncline plunging 24° NE.

There is a possibility of a second syncline on Keller Hill with its axis about midway in the "greenish quartzite" of the Montalto Member near Mount Holly Gap. This possibility could be inferred from the similarity of the Antietam Quartzite and the "vitreous quartzite" unit. In the core of the anticline in Mount Holly Gap, the northwest limb of the anticline is composed of the three lentils. If there were a syncline northwest of these, what is labeled the Antietam Quartzite would become the "vitreous quartzite" unit and there would be a set of lentils for the northwest limb that matched the lentils in the core of the anticline. The area mapped as "greenish quartzite" has abundant large float of "blue quartzite" which could have rolled downhill from peak 1133 or could have come from the northwest limb not far out-of-place. The absence of "foliated quartzite," the presence of the Harpers phyllite unit, and the faint differences in lithology between the Antietam Quartzite and the "vitreous quartz" ruled out the possibility of a second order syncline here. All rocks northwest of the axis of the Mount Holly anticline are on the northwest limb of the Mount Holly anticline.

The Benders quarry anticline is named for the sand pit excavated along its plunging axis. It is asymmetric steepening to 79° on the northwest limb with third-order folds on its flanks. The delineation of the fold and the evidence that it is doubly plunging was derived from the following data: 1. the boundaries from differential erosion lines on an aerial photograph, 2. a number of chip traverses across the fold, and 3. delineation of "blue quartzite" boundaries from Spruce Run southwest to the crest of the next hill by observations of float. The Harpers phyllite unit may be indicated in this fold by the topographic depression southwest of the Antietam Quartzite ridge along the north edge of Mount Holly. A third-order syncline indents the topography and an anticline forms another spur west of Benders Quarry. A few outcrops and a subsidiary quarry in Antietam Quartzite southeast of the Benders quarry anticlinal axis indicate a plunging syncline.

The plunging spur at the northeast end of Trench Hill is a second-order fold. Just north of it an indentation in the topography marks either the next or a subsidiary syncline in "vitreous quartzite." Dashed line contacts on Trench Hill are based on topography and taken from aerial photographs. If the topography can be relied on to define structure, the southwest curving lines would indicate southwest plunges, and Trench Hill would be doubly plunging.

Antietam Quartzite in the quarry at the sharp bend in Route 94 south of Upper Mill is anticlinal. Faint lines in an aerial photograph suggest a syncline plunging southwest north of the anticline.

FAULTS

Strike-slip and Thrust Faults

G. W. Stose (1953) drew the following faults on the Carlisle (15′) quadrangle: Cold Spring thrust, Laurel Forge thrust, Reading Banks thrust, Mt. Tabor thrust, and the Triassic border fault. He stated that all faults except the Triassic border fault were thrust faults.

Each of Stose's "thrust" faults are considered below. Only two of the faults, the Cold Spring Run fault and the Reading Branch thrust, show characteristics of thrust faulting. The irregular northwest border of Mount Holly could be associated with the overthrusting or with folds plunging under the Tomstown Dolomite. As the Cold Spring Run fault, which marks at least part of the northwest border of Mount Holly, is apparently a strike-slip fault, and there is abundant evidence of numerous plunging folds, the latter interpretation seems more logical. The Reading Branch thrust of Stose (1953) has been re-aligned in this study to coincide with the very irregular boundary at the northwest edges of Piney Mountain, Trent Hill and Trench Hill. This irregular boundary, coupled with the breccia in the Antietam Quartzite at the northwest edge of Piney Mountain, is the most striking evidence for a thrust fault in the Mount Holly Springs quadrangle. The evidence favors a thrust with a moderate angle of dip as indicated in the cross sections, Plate 1.

The presence of quartz- and limonite-cemented outcrops of breccia in Antietam Quartzite on the north edges of Mount Holly and Piney Mountain and breccia float on the slopes of Cold Spring Run suggest the possibility of thrust faults in these areas. Because the breccia is essentially massive and structureless (Fig. 22), it may represent a sedimentary breccia. However, similar, though less well-cemented, breccias at the base of the Pulaski thrust block in Pulaski County, Virginia, were observed by the author and described by Cooper (1961, p. 86). Another observation in favor of a thrust here is that the location of the breccia outcrops at the north base of Mount Holly and Piney Mountain is where a breccia would exist if thrusting had occurred.

The Cold Spring Run fault appears to be a left-lateral, strike-slip fault which, instead of continuing into the carbonates of the Cumberland Valley as Stose indicated, marks the northern edge of Mount Holly at least as far as Benders quarry and possibly further. The stratigraphy requires no fault along the northern edge of Mount Holly, but the line of the fault can be followed on the aerial photograph. In Cold Spring Run, Antietam Quartzite on the west apparently abuts against the

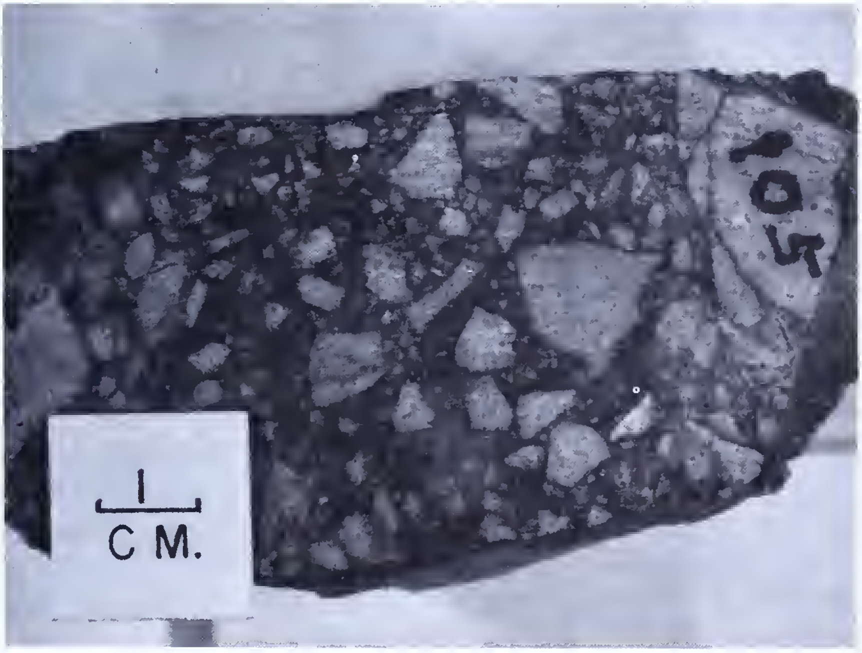


Figure 22. Hand specimen of brecciated Antietam Quartzite cemented with silica and limonite. Collected on northwest flank of Mt. Holly, 3200 feet east of Mt. Holly Springs reservoir.

"greenish quartzite" of the Montalto Member to the east with a distinctly different attitude. The only other observable evidence of the fault is the breccia of Antietam Quartzite cemented with quartz and limonite (Fig. 22). The dip of the Cold Spring Run fault is apparently fairly steep as deduced from its smooth curve across changes in topography. There is little that precludes this fault from being a splay of a thrust fault that could underlie South Mountain, but it lacks the typical characteristics of a thrust.

The validity of the Laurel Forge thrust is doubtful. There is a break in topography and structure at its northern end. On the aerial photograph an offset can be observed in the plunging nose of the Benders quarry anticline. The valley southward may be a continuation of this offset. There is evidence against the fault line drawn by Stose (1953) but very little to indicate the direction of its continuation. The offset in the Benders quarry anticline indicates possible left lateral strike-slip movement and a steep attitude.

The southwest end of the line of the Reading Banks thrust (Stose, 1953) marks the southeast boundary of the Loudoun and Weverton Formations. The contact between muscovitic phyllite and the Weverton Quartzite is exposed on the line of the Reading Banks thrust at the Goodyear muscovitic phyllite pit. This contact is knife-edge sharp and is conformable. A section in the Weverton Quartzite from its contact with grayish-lavender muscovitic phyllite follows:

Tape traverse into Weverton Quartzite from the contact between muscovitic phyllite and basal Weverton Quartzite in the Goodyear muscovite pit

Distance	*Description*
0-1′	Pebbly pale-purple quartz-muscovite quartzite with pebbles up to 5 mm becoming as fine as 2 mm.
1′-2′	Muscovite-quartz phyllitic quartzite with green muscovite and pale-purple, poorly sorted, sand grains ranging to 3 mm.
2′-3′6″	Pebbly quartz-muscovite quartzite with irregularly and poorly sorted quartz grains to 1 cm and lavender rhyolite pebbles to 2 cm.
3′6″-	Alternations of fine-grained quartz-muscovite phyllitic quartzite with muscovite-coated quartz grains (average diameter, 0.1 mm, maximum 1.0 mm) Alternations at 6″-1′ intervals.

There is a gradation from coarser to finer upward in the section which verifies the inferred overturned relationship of the two formations. Northeastward in the Carlisle quadrangle, Stose ends a number of formations against the Reading Bank thrust. Similarly in the Mount Holly quadrangle a fault is required in part along the line of Stose's Reading Bank thrust. It is realigned in this study to cut the length of Trench Hill, Trent Hill and Piney Mountain. The Trench Hill fault is probably a splay of the Piney Mountain thrust.

The only evidence for the Mt. Tabor thrust (Stose, 1953) is a line of en echelon outcrops and ridges on the north peak of Fickles Hill. The fault may be valid, but en echelon ridges striking about N45°E would indicate a shear fault rather than a thrust. The evidence was too local to plot the fault at the scale of the geologic map (Plate 1).

No faults were observed along the Triassic border. Stose (1953) explains the discrepancy between proposed deep down-dropping of Triassic sedimentary rocks and the presence of underlying Paleozoic limestones at the surface by step faulting. In this interpretation, Paleozoic limestones floor the Triassic sedimentary rocks at shallow depths near the border fault, but are deeper further away.

In addition to the faults proposed by Stose (1953) a number of others are proposed in this report. The Clay Pit fault is one of these. The south border of Mount Holly is composed of a number of different rock units from Antietam Quartzite to the "foliated quartzite" of the Montalto Member, all of which are in contact with the younger Tomstown Dolomite. The Clay Pit fault which is clearly delineated in aerial photographs has been drawn on Plate 1 along this line. As pitting has exposed a vertical wall of "vitreous quartzite" (Montalto) and the fault crosses varied topography with little divergence, the fault is presumed to be vertical. It cuts across folds in Tomstown Dolomite and vitreous quartzite and could be the late stage result of either folding or thrust faulting.

Trench Hill gets its name from a sharp depression shown by the contours that run the full length of the hill. Piney Mountain has a main ridge and a secondary one on the west slope with a depression between them. The area southeast of Toland has two low peaks separated by a depression, and Trent Hill also has a depression between peaks. In an area where differential erosion is controlled by rock type and structure, such depressions must have compositional or structural meaning. As no difference was observed in the composition of the rock float on either side of the depression on Trench Hill, a fault is implied. This fault which is vertical (based on its straight contact across varied topography) is probably a splay of the Reading Banks thrust.

A short fault parallel to the regional trend offsets the northwest limb of the Rocky Ridge syncline. It shows on the aerial photograph as an offset ridge and bedding attitudes close to the fault indicate a drag of the northwest side to the northeast.

Weverton Quartzite on the northwest edges of The Peak and Long Mountain are in contact with lavender aporhyolite and aporhyolite porphyry. Either no Loudoun Formation was deposited there, the contact is an erosional unconformity, there is a facies change from Loudoun to Weverton, or there is a fault. The steep slope also indicates a possible fault which would have dropped The Peak and Long Mountain relative to the volcanic rocks.

Transverse Faults

Four essentially parallel faults are proposed across Keller Hill: Mount Holly Gap, the northwest-southeast depression in line with the ruins south of Keller Hill, and two closely spaced faults at the northeast end of Keller Hill. The principal reason for presuming a fault in Mount Holly Gap is that the topography and prominent outcrops are offset at both ends of the Gap and a gap of such proportions could be fault controlled. From the offset and the linearity of the gap, the fault should be right lateral with strike slip movement and essentially vertical dip. That the fault continues southward is suggested by the abrupt termination and shattered texture of the Antietam Quartzite ridge at the bend of Route 91. The next transverse fault northeast on Keller Hill is marked by a depression on the south slope and a less-well-marked one on the north slope. There is also a suggestion of offset at each end. Stratigraphic correlation inferred from the geologic map (Plate 1) would indicate a fault but the actual presence of strata shown to the northeast of the fault are based on lineaments on aerial photographs and stratigraphic requirements rather than on observation. The area is covered with rubble from the hills and there was no reliable indication of the underlying rock types. The continuation of this fault southward is marked by two low areas on Trench Hill directly in line with it. It too is presumably a vertical, right lateral fault. The next two faults northeastward are marked by indentations in the perimeter of the nose of the Mount Holly anticline, a low area between them on the high ridge in line with peak 1281, a depression and a steep slope across Trench Hill and lineaments in aerial photographs. Based on direction of movement of the outer edge of the Antietam Quartzite, the north end of the two faults looks like a graben.

The most northeasterly fault continues southward to cut a steep slope on the southwest end of Rocky Ridge and to raise the synclinal structure of The Peak so that it eroded to a narrower exposure than on Long Mountain northeast of the fault. This suggests a hinge fault, rising in the southeast part and dropping in the northwest.

Two small northeast-southwest-trending transverse faults in Antietam Quartzite are indicated on aerial photographs. Antietam breccia crops out on the northwest slope of Piney Mountain along the traces of these faults.

In summary, the Reading Banks thrust is thrust over the Tomstown Dolomite with a moderate angle of dip. Mount Holly may be an overthrust block but is more likely formed by folding with strike-slip movement at Cold Spring Run. The Clay Pit fault is probably a higher angle splay of the Reading Banks thrust or caused by relaxation of pressures.

The transverse faults probably developed as extension features of the region or as differential responses to resistance to folding. It is probable that other faults, which were not actually observed because of the scarcity of outcrops, cut the volcanic rocks.

Joints

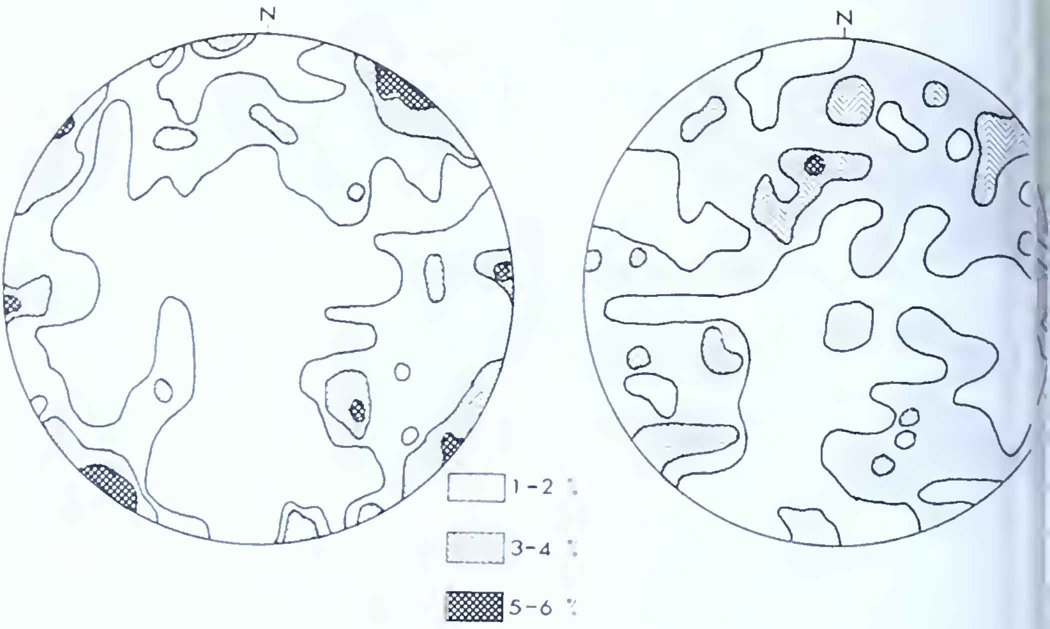
Joints are a common feature in all the rocks in the quadrangle (Fig. 23). One hundred joints were measured in "vitreous quartzite" of the Montalto Member of the Harpers Formation at the south end of Mount Holly Gap. Strike maxima of these joints occur at N45°E as extension joints parallel to the regional trend, N45°W perpendicular to the regional trend, and E-W joints indicating essentially two sets of perpendicular vertical joints and another vertical set bisecting them. When plotted on an equal area net smaller concentrations of joints make an almost complete girdle around the circumference. There also is a partial girdle indicating more gently dipping joints which trend about N50°-60°W. Other joints range widely in strike and dip. A plot of joint planes measured in Antietam Quartzite at the sharp bend in Route 94, south of Mount Holly Springs, show a considerable scatter in orientation. This may be accounted for by faulting which apparently shattered the outcrop and thus destroyed any orientation which the joints might have had.

An equal area net of the poles to 100 joint planes in the Antietam Quartzite was made at Benders quarry (Fig. 23). The net shows the greatest concentration of poles at N40°E with steep to vertical dips. This orientation is parallel to the regional trend and to the axis of the Benders quarry anticline. A northeast-southwest-trending girdle indicates a set of joints fanning across the anticlinal axis. A third set strikes northwest and dips moderately to steeply to the northeast and southwest probably representing an extension joint which resulted from folding.

Equal area nets of the poles to joint planes from all rock types duplicate those above to some extent. The major difference is an almost complete girdle around the circumference of the net, representing moderately to steeply dipping joints.

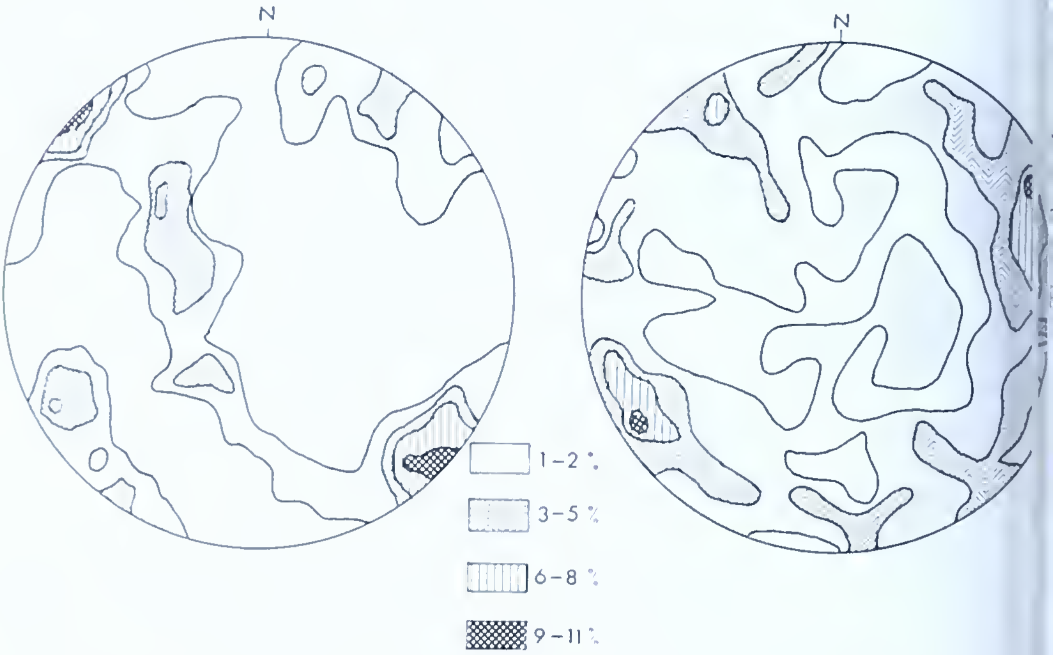
TECTONIC CONSIDERATIONS

The origin of South Mountain and the principal mechanisms for its uplift have been the subject of debate. Geiger and Keith (1891), Keith (1894) and Stose and Stose (1946) interpreted the structure of the Blue Ridge and South Mountain to be a synclinorium with an overthrust block at Harpers Ferry. Cloos (1947, 1951), working in Washington County, Maryland, interpreted the structure as an anticlinorium with the normal limb on Catoctin Mountain and the overturned limb in the Blue Ridge and South Mountain.



100 joints in Montalto Quartzite, south end of Mount Holly Gap

100 joints in Antietam Quartzite, Route 94 at sharp bend south of Mount Holly Springs



100 joints in Antietam Quartzite, Benders quarry on NW side of Mount Holly

177 joints from Antietam, Montalto, and Weverton Formations and the volcanic rocks

Figure 23. Equal area nets of joints in the Mt. Holly Springs quadrangle.

The suggestion has been made (personal communication, Arthur Socolow) that South Mountain in Pennsylvania (Fig. 2) is a thrust block which slid over the clayey Tomstown Dolomite. Mount Holly is surrounded by Tomstown Dolomite on three sides, northwest, northeast and southeast (Fig. 2). In the Philadelphia Clay Company pit at Toland, a contact of "vitreous quartzite" (Montalto) over Tomstown Dolomite clay was observed. This contact ran almost the full length of the pit. Because the quartzite should underlie the clay, this is an anomalous relationship. In numerous drill holes in the clay pit, the drill penetrated quartzite before clay. Two possible solutions are (1) a local landslide block of quartzite slid down the side of Mount Holly over the clay, and (2) Mount Holly is an enormous thrust block which slid over the clay and is resting on and surrounded by it (Fig. 2). The second solution can be expanded to explain the structure of South Mountain as suggested by Socolow.

A study of the clay pit utilizing the equal area net plot of structures (Plate 2, Fig. 3) suggests that a large block of "vitreous quartzite" slid down over the clay. Figure 24, shows the northeast end of the hill from which the slide block separated and stereoscopic observation of aerial photographs shows the depression in the mountainside from which the slide block came. Subsequent quarrying at the southwest end of the pit showed the clay in fault contact with an extensive vertical wall of quartzite.

Keller Hill and Mount Holly, sandwiched between the Cold Spring Run fault and the Clay Pit fault, are almost completely surrounded by faults. If these are low-angle faults, this could be evidence that they represented a nappe thrust over the surrounding and presumably underlying Tomstown Dolomite. The inferential evidence against this interpretation is as follows:

1. The faulting does not completely surround the nose of Keller Hill. Although no contacts were observed in the field, Tomstown Dolomite apparently conformably overlies the Antietam Quartzite on the nose and northwest side of Keller Hill, and may underlie part of the northwest side of Mount Holly.
2. The fold axial planes appear to be steeply dipping rather than overturned to recumbent.
3. In the only place that the Clay Pit fault was exposed (at the Philadelphia Clay Company pit), the contact is essentially vertical. This indicates a high-angle fault rather than a thrust fault.

Cloos (1950) stated that thicker portions of the South Mountain anticlinorium were caused by additional folds rather than by thrusting. This is true at Mount Holly where the Benders quarry anticline and nearby

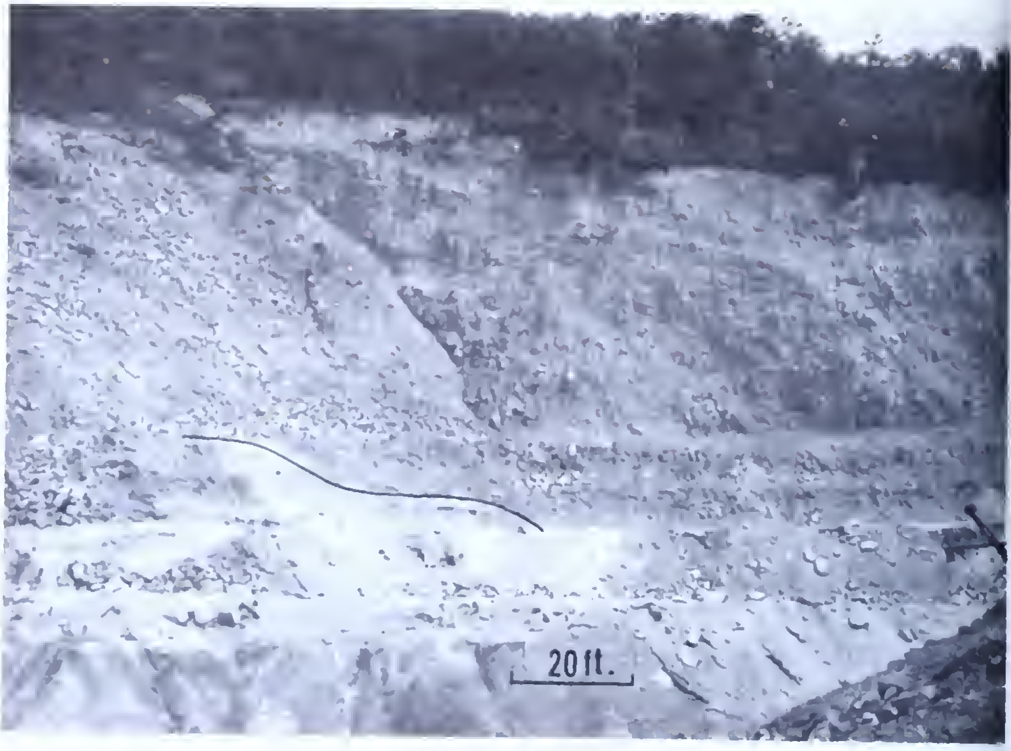


Figure 24. Philadelphia Clay Co. pit showing Manalto Quartzite slide block resting on clay derived from the Tomstown Formation. Line indicates contact.

folds cause a considerable widening in the mountain. Another cause of widening may be movement of parallel blocks of the folds out along strike-slip faults similar to the Cold Spring Run fault.

Fossils date the age of Antietam Quartzite as early Cambrian and the other formations are considered to have been deposited in the same epoch, with the possible exception of the volcanic rocks. The latter were probably not folded prior to deposition of the clastics.

All of the rocks have similar structures consistent with their competence. Pure quartzites exhibit bedding planes, joints, and deformed *Skolithus* tubes. Impure quartzites show bedding, one flow cleavage fracture cleavage, and joints. Strongly pelitic rocks exhibit bedding planes, more than one flow cleavage, and joints. These structures may have been produced during successive stages of one deformation or during different deformations.

Freedman and others (1964) present evidence in favor of multiple deformation in the Piedmont to the southeast. Similar structures (Plate 2) in the Mount Holly quadrangle may mean multiple deformation.

Lapham and Bassett (1964, p. 661-668) report ages of 460 m.y. and 330 to 350 m.y. from K/A dates from micas and whole rock samples in the Piedmont. These ages probably represent the ages of at least two deformations undergone by rocks in the Blue Ridge province.

GEOLOGIC HISTORY

In Late Precambrian or Early Cambrian time it is probable that the basement gneiss was exposed in the Mount Holly Springs quadrangle. Volcanoes erupted and feeder dikes spewed basaltic lava in thin flows across the area interspersed with occasional ash falls. These hardened to interlayered basalt and basaltic tuff in the southeastern part of the quadrangle. Sufficient time may have elapsed to develop a soil on the lava flows which later became black phyllite layers, before the extrusives changed in composition to rhyolite. Extrusion was intermittent; now extruding lava that was all liquid, producing rhyolite; later permitting crystallization of quartz and/or feldspar in the magma chamber before extrusion, producing rhyolite porphyry. Intermittently, basaltic lava was extruded again as evidenced by interlayered aporhyolite and metabasalt in the Big Hill area in Menallen Township. The purple phase of rhyolite extrusion is the youngest and may reflect an extrusion concomittant with surficial oxidation of longer duration than existed for the other rhyolite flows.

By Early Cambrian time extrusion had ceased, and erosion, probably of short duration, exposed the basement and volcanic rocks to weathering. This provided quartz, kaolinized-feldspar, and fragments of volcanic rocks to streams which washed them into a sea encroaching on the land from the east. Wave action sorted the sediment into quartz-rich and kaolin-rich layers. Low relief or distance from source areas gradually increased the amount of kaolin until it was dominant.

A surge of uplift brought pebbles of white and lavender vein quartz and quartzite, angular pebbles of lavender rhyolite and much quartz sand and kaolin to the sea. These were only partly sorted before more sediment washed in on them accumulating into what is now the poorly sorted Weverton Quartzite.

The deposition of small amounts of kaolin with clean sand caused accumulation of the "foliated quartzite" unit. Pre-existing sandstones must have been exposed to erosion to produce the high-purity quartz sands that make up the "vitreous quartzite" unit of the Montalto Member. These sands were exposed on beaches in which *Skolithus* tubes were formed. More sand and small amounts of feldspar, kaolin and magnetite accumulated to form the "blue quartzite." The sediment became increasingly and intermittently finer grained as sandstone, shaly sandstone and shale were deposited to form the "greenish quartzite." With deposition becoming progressively finer and more kaolinitic and/or micaceous with local deposits of clean quartz silt, the sediments were deposited which later became the Harpers phyllite.

Either a change in direction of stream transport renewed exposure of pre-existing sandstones, or long transport from the weathered basement complex produced first the arkosic Antietam Quartzite and finally almost pure quartz sand in which again *Skolithus* tubes were formed.

In early Middle Cambrian time, sediments quickly became finer and finer, until so little mud was brought to the sea that minute animal shells accumulated into beds of limestone. Through diagenesis, or later replacement, some limestone was altered to dolomite and some to chert. Thin beds of limestone, dolomite and shale accumulated to form the Tomstown Dolomite.

Succeeding limestones of the Cambrian Waynesboro, Elbrook, Conococheague and the Ordovician Beekmantown, "Stones River," and Chambersburg Formations once may have been deposited on the Tomstown Dolomite in this area but have since been eroded away. The Martinsburg Formation may also have been present.

Probably after deposition of the Martinsburg Formation in Late Ordovician time (about 460 m.y. ago) tectonic activity folded the area. This may be D_1. The volcanic and sedimentary rocks were metamorphosed to metabasalt, aporhyolite, muscovitic quartzite, muscovitic phyllite, muscovitic pebbly quartzite, various quartzites and interbedded marble and phyllite. The folds were overturned and minerals were aligned in planes of flow or oriented in tectonic "a." Later, either in the same deformation or in a later deformation, possibly D_2, further tectonic activity developed secondary flow, or shear cleavages. During Triassic time sediments accumulated in basins. Faulting dropped the basins on the north, possibly in a series of step faults. Later, Triassic sediments piled on top of Paleozoic limestones which had been exposed by erosion following orogenesis. Toward the end of Triassic time, sheets of diabasic magma intruded the sediments. Pressure from the magma chamber forced this magma into joints trending north-south. At least three such dikes formed in this area.

Erosion removed overlying rocks throughout Cretaceous time, followed by isostatic uplift of the mountains in Late Cretaceous time. Erosion cut into the less resistant limestones and volcanic rocks, reducing them to lower levels and etched out the resistant quartzites holding up the mountains.

Glaciers did not override the quadrangle, but the periglacial climate probably caused much greater precipitation and frost action than at present. Rock slides such as that at the Philadelphia Clay Co. pit (Fig. 23) may be related to the more severe climatic conditions existing during glacial times.

An exceptionally deep fill of alluvial material near Mt. Holly Springs may be related to increased water activity during glacial times. The record of a 419-foot bore hole (Table 4) drilled for water by the Schweitzer Division of Kimberly-Clark Paper Company on the bank of Mountain Creek at the north end of Mt. Holly Gap shows a fill of at least 419 feet of gravel, sand, and clay. This anomalously deep fill can be explained perhaps by the reaction of ground water moving downward through Antietam quartzite beds which crop out on Mt. Holly. At depth, water enters into fracture zones in the Tomstown dolomite and dissolves away the rock leaving behind an insoluble residue. Fracturing of the Tomstown would be greatest in line with the fault zone through Mt. Holly Gap. The volume change caused by loss of dissolved material and by differential compaction would cause a sag at the surface; the sag would be quickly filled by stream-carried material. Water activity through the gap at the surface, and on the subsurface, would have been increased during glacial times. A subsequent increase in the rate of solution might accompany the increased water activity. Lowered water temperature might likewise have contributed to solution of carbonate bedrock.

Table 4.—*Log of 6½″ diameter test hole.*

LOCATION: Mt. Holly Springs, Pa. on bank of Mountain Creek, property of the Schweitzer Division of the Kimberly-Clark Paper Co.

LOG BY: W. G. Chapman for Kohl Bros. Co.

RIG USED: Shramm TMOR #73 DRILL COLLAR: 570 feet above mean sea level

WORK BEGAN: 12/10/59; ENDED: 12/17/59

Depth of strata (feet)	*Formation penetrated*
9	Coarse gravel, boulders, clay
22	Coarse gravel, sand, yellow clay, boulders
50	Yellow sandy clay, large gravels
70	Sandy yellow and red clay
91	White soft sandy clay
114	Tough hard white clay
132	Fine gravel, streaks clay
144	Hard white clay
150	Fine gravel, streaks clay
180	Hard tough clay
235	Sandy clay, streaks hard clay
268	Gravels, streaks of clay
272	Hard clay
276	Gravel, broken rock, clay
337	Sand, gravel, clay streaks
357	Gravel, broken rock, clay
419	Clay, broken rock, gravel

ECONOMIC GEOLOGY

White clay, sand, and muscovitic phyllite are the only presently produced economic products in the Mount Holly Springs quadrangle. In the past limestone was quarried from the west slope of Piney Mountain and from quarries now water-filled east of Gardners, and between Snyders Hill and Millers School. It was used for fertilizer and in the production of quicklime for mortar.

Numerous pits occur on all slopes where Tomstown Dolomite overlies Antietam Quartzite. Limonite leached from Tomstown Dolomite impregnates the beds overlying the Antietam Quartzite and forms irregular masses and nodules in the residual clay. The nodules and masses were washed from the clay and formed a siliceous iron ore concentrate. Numerous water-filled pits in Mountain Creek Valley mark locations of the more extensively worked pits. Many smaller pits dot the mountain slopes. No limonite is being mined today. Volcanic rock is quarried locally for nearby use as roadmetal and fill.

The Antietam Quartzite is very deeply leached which is remarkable for so tough a quartzite. The reason may be that ground water seeping down through the overlying Tomstown Dolomite became alkaline and able to dissolve silica. Sand pits on the northwest slope of Mount Holly are being extensively worked. Benders quarry has 8 levels along the plunging axis of the Benders quarry anticline, where a vertical fault along the axis opened and shattered the surrounding quartzite permitting ground water to leach the silica cement. To some extent it deposited limonite which is deleterious for making mortar. The quarry owners blast and truck quartzite to the foot of the mountain where the weathered rock is crushed and screened. The sand sells for $1.50 per ton (1963).

Another large series of sand pits is at the end of Hill Street in Mount Holly Springs. During 1961, a firm constructing a four-lane highway south of Carlisle leased these pits from the Bender family and removed thousands of tons of sand and rock. The material is almost entirely talus washed off Mount Holly. The pits were worked until the residual clay of the Tomstown Dolomite was encountered; rarely was bedrock exposed. The clay was tested for white cement but didn't meet specifications.

White clay has been produced since before the turn of the century (Stose, 1907a). Most of the production is from the deposits at Toland which were first mined underground but are now being worked in open pits. Stose (1953) speaks about the origin of the white clay as follows: "White clay was observed in most of the old limonite pits years ago, but it was not mined until about 1890. The clay is derived from disintegrated sericite schist, a bedded deposit at the top of the Antietam

Quartzite, directly underlying the limonite deposits in the clay residual from the Tomstown Dolomite. The whiteness of the clay and freedom from iron may be due in part to leaching of the iron from the schist to form the limonite." However, present quarrying at the Toland pit of the Philadelphia Clay Company, shows that the white clay occurs in a thick distinct bed which seems interbedded with Tomstown Dolomite, rather than originating from a sericite schist. Some of the leached Tomstown Dolomite is variegated with or includes nodular masses of manganese (Figure 25). Only limited extension northward of the white clay has been found by drilling.

The white clay may be derived from layers in the Tomstown Dolomite which had only kaolin insolubles. Bedding in Tomstown Dolomite dips steeply in the pit and may have offered easier ingress to ground water for removing impurities than was possible in the mostly recumbent portions of the formation. The broken and deeply weathered slide-rock of "vitreous quartzite" may have supplied acidic ground water in greater volume to the underlying Tomstown Dolomite than was possible for that exposed at the surface.

The white clay is used for making white Portland cement. The Philadelphia Clay Company sells its total production to the Medusa Cement Company for $6.00 per ton (1963). The Philadelphia Clay

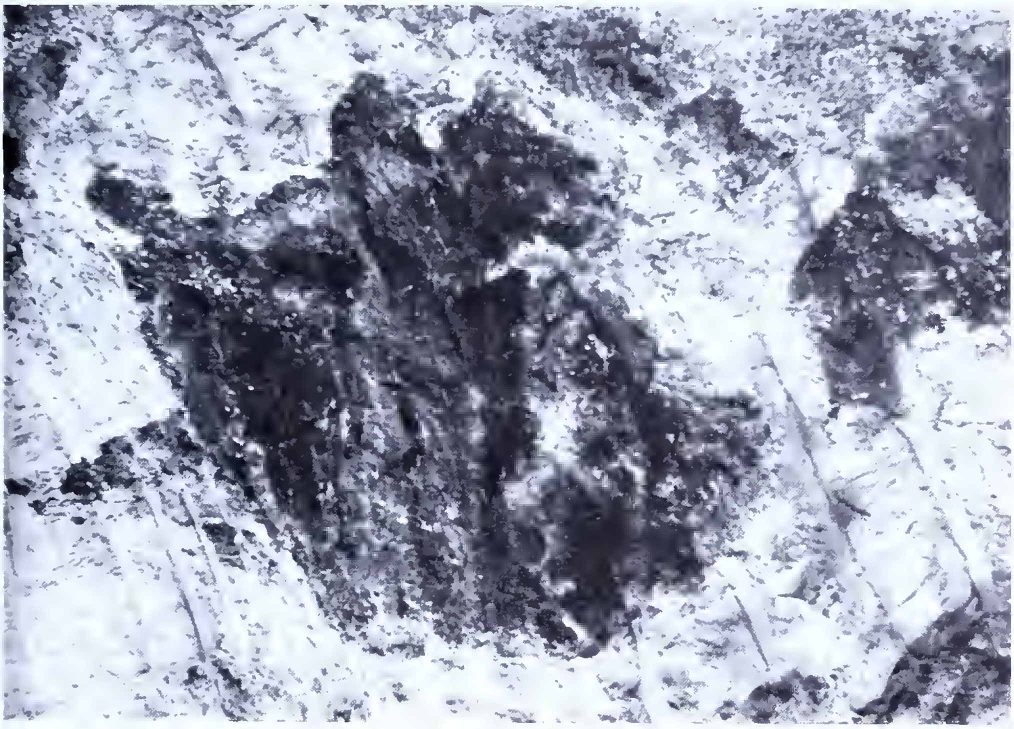


Figure 25. Limonitic and manganese oxide nodules in clay. Power shovel tooth marks and view of the same nodule in Figure 15 give the scale.

Company has to move about six loads of impure clay for each load of pure clay. Mountains of waste clay, which are suitable for brick manufacture, have been stockpiled. It might also be possible to separate the white from the waste clay after pulverizing.

Stose (1953) stated: "Certain resistant beds in the volcanic slate, so-called soapstone (sp), was quarried locally on Hunters Run, 1 mile northwest of Zion Church, and was used in the construction of lime kilns." He refers to muscovitic phyllite which was called soapstone and pyrophyllite from its resemblance to talc. Lapham (personal communication) X-rayed some of the material and found it to be muscovite. Some pyrophyllite as reported by Stephenson (1950) is also present. Areas underlain dominantly by muscovitic phyllite are shown on Plate 1. Two areas have been quarried for use as insecticide carriers. The one mentioned above by Stose has been referred to as the Goodyear muscovite pit in this paper (Plate 2, Fig. 4). The second is the Gargol muscovite pit (Plate 2, Fig. 5) north of the Gargol intersection on the Eva Pape fruit farm. On August 27, 1962, the Mauna Mining Company started grinding muscovitic phyllite and pyrophyllite from the Gargol pit at a plant at Hunters Run, South Middleton Township. Production has been intermittent. Test runs were made at Dillsburg by the owner, Mr. L. P. Lucy, of Littlestown, Pennsylvania.

Lenses of milky quartz, 20 to 50 feet thick and about 200 feet in length occur 1. south of Uriah School (3 lenses), 2. north of Myerstown (3), 3. at the bend in the road north of Uriah, and 4. east of Route 94 about in line with the southeast edge of Rocky Ridge (2). A total of 9 lenses of quartz constitutes a potential for commercial exploitation for ground silica or terrazzo. They are surrounded on the surface by numerous large quartz boulders. Other areas with large quartz boulders may signify other lenses which were not observed.

Phosphate (wavellite), manganese oxides, and native copper have been reported by Stose (1909) and Stose and Bascom (1929). No observations of these were made during this investigation.

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